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THE POTENTIAL APPLICATION OF GEOTEXTILES IN THE CONSTRUCTION OF OFF-HIGHWAY ROADS

Richard J. Kolada

March, 1987

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THE POTENTIAL APPLICATION OF GEOTEXTILES IN THE CONSTRUCTION OF OFF-HIGHWAY ROADS

by

Richard J. Kolada

ABSTRACT

This paper reviews the use of geotextiles with respect to the construction of mine haulage roads.

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UTILISATION POSSIBLE DES GÉOTEXTILES DANS LE DOMAINE DE LA CONSTRUCTION DES VOIES DE ROULAGE POUR L'EXPLOITATION MINIÈRE

par

Richard J. Kolada

RÉSUMÉ

L'étude porte sur l'utilisation des géotextiles dans le domaine de la construction des voies de roulage pour l'exploitation minière.

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CONTENTS

	Page
ABSTRACT	i
RESUME	iii
CONTENTS	v
INTRODUCTION	1
HISTORY	1
TYPES OF GEOTEXTILES	2
GEOTEXTILES IN ROAD CONSTRUCTION	2
Reinforcement	3
Subgrade Separation	6
Subgrade Drainage	8
Design Criteria of Road Employing Geotextiles	8
DISCUSSION	8
CONCLUSIONS	9
REFERENCES	9
APPENDICES A,B, AND C. AN EXAMPLE OF GUIDELINES FOR THE USE OF GEOTEXTILES IN ROAD CONSTRUCTION	11
APPENDIX D. METHODS OF TESTING GEOTEXTILES	53
Tensile Strength	54
Soil-Geotextiles Friction and Adhesion	54

FIGURES

Fig 1	Conceptual Illustration of Mechanisms by which Geotechnical Fabric Improves Road Performance. After Haliburton and Fowler (5)	4
Fig 1a	Fabric Separation Prevents Deterioration of Planned Design	4
Fig 1b	Fabric Lateral Restraint improves cover material Performance	4
Fig 1c	Fabric "Membrane" support carries part of wheel load	4
Fig 2	Two types of tests performed using a shear box: (a) Shear Test; (b) Pull-out test	7

INTRODUCTION

The Surface Mining Laboratory of CANMET has initiated a program of research to improve the productivity of surface mine large off-highway truck fleets. This work is of considerable importance due to the large operating costs associated with such equipment. This program of research includes the examination of haulage road construction techniques and their effect on road rolling resistances which is a major controlling factor of the productivity of haulage fleets.

The predominant method of constructing mine haulage roads involves the use of suitably compacted aggregates. However, at many mine sites, there may be a limited quantity of aggregates of acceptable quality. Anoth problem that can aggravate this situation is the occurrence of land surfaces that are of low strength. This requires a large amount of aggregate in order to spread vehicle loads over the soft ground. Alternatively the ground can be excavated to a depth where the eventual road bearing surface (subgrade) is of sufficient strength. Both of these remedies increase the cost of construction. Further, if an aggregate road is constructed over a weak subgrade it may deteriorate fairly rapidly. This results from ground and water pressures pushing the weak subgrade material into the matrix of the aggregate and hence causing a deterioration in the aggregate strength. One possible solution to these problems that has only been developed recently is the use of geotextiles. This paper examines the benefits and disadvantages of employing geotextiles in the construction of mine haulage roads.

HISTORY

Geotextiles were originally referred to as "fabric filters". The first major application of these fabric filters for geotechnical purposes occurred in the 1960's where they were used for erosion protection of Palm Beach in Florida. Since then the use of fabric filters for the prevention of erosion has gained popularity especially for river bank protection. In the 70's and 80's civil engineers began to examine the use of these fabrics for other purposes and the name "geotextiles" was adopted. It has been reported in the literature that during this time period the use of geotextiles at mine sites has increased significantly, especially in the

Eastern Coalfields of the United States (1). The reasons cited for this are: the ease of installation, availability and cost effectiveness in comparison to the more common graded stone filters. The fabrics are being used primarily in the coal refuse disposal embankments, sediment control structure and for haul road stabilization.

TYPES OF GEOTEXTILES

There are three basic types of fabrics:

1) Woven fabrics of two series of threads perpendicular to each other. The threads may be either of circular cross-section or thin strips cut from a film.
2) Knitted materials that consist of a single thread that is systematically entwined with itself.
3) Nonwoven material consisting of threads placed at random. They are bonded together either chemically, by heat and compression, or mechanically by spunbonding, needlepunching or the application of resin. (Needlepunching entangles the threads with a machine that has thousands of specially shaped needles.

All of these fabrics are made from synthetic material since the useful life of natural fibres is too short. These fibres are normally made from polypropylene, polyester, nylon or polyethylene.

GEOTEXTILES IN ROAD CONSTRUCTION

Geotextiles have been used in the construction of aggregate roadways with the intention of providing the benefits listed below:

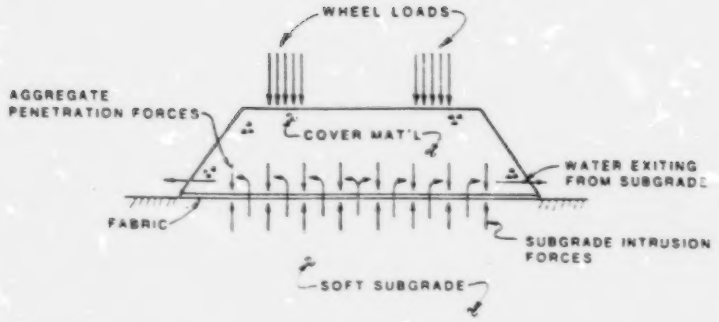
a) To prevent fine subgrade soil from penetrating into the matrix of the aggregate base and degrading its strength and supporting ability, (Figure 1a).
b) To provide a drainage path between the subgrade and the aggregate layer. This will reduce water pore pressure of the subgrade and therefore increase its strength, (Figure 1a).
c) To provide tensile reinforcement of the road structure. This prevents the base of the cohesionless aggregate layer from "spreading out", (Figure 1b).

d) If the tensile is deformed under the wheel path and a tensile strain is developed in the material, it will produce a counter active stress against the wheel load. (Figure 1c).

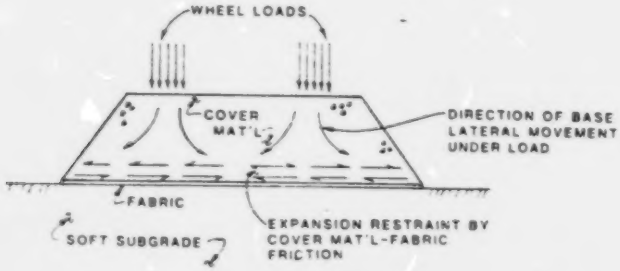
REINFORCEMENT

The interactions between a geotextile and the various layers of roadway material is complex and not fully understood. There are however three basic mechanisms that have been identified whereby a geotextile can reinforce a road:

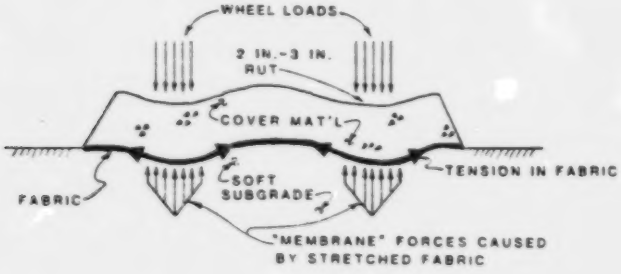
1) The geotextile will warp or rut under a vehicle load as shown in Figure 1c. This warped shape tends to constrain the material under the wheel from lateral spreading and so helps to prevent rutting and further deformation of the road. This fabric shape can be deliberately designed to occur in order to take maximum advantage of this effect.
2) When a load is applied to the surface of a road the stress will be distributed through cohesionless aggregate to the aggregate-subgrade interface. If the subgrade is weak, the load stress will induce the aggregate particles at the interface to spread apart in a lateral direction. However, if a geotextile and the aggregate will result in a confining stress that will increase the load bearing capacity of the aggregate and distribute the load over a greater area of the subgrade. Perhaps a useful analogy of this mechanism would be a tensile reinforcement bar used to strengthen concrete.
3) If a geotextile is properly anchored and deformed under the wheel path, large tensile strains can be induced which in turn produces a stress normal to the fabric. Directly under the wheel this stress is in opposition to the wheel load. This stress is generated by the fabric pushing down on the outside edges of the rut or depression. The net effect is to spread the load and retard rutting. The amount of stress produced by the fabric against the wheel load will depend on the amount of deformation, and the tensile strength, tensile modulus and the



A. FABRIC SEPARATION PREVENTS DETERIORATION OF PLANNED DESIGN



B. FABRIC LATERAL RESTRAINT IMPROVES COVER MATERIAL PERFORMANCE



C. FABRIC "MEMBRANE" SUPPORT CARRIES PART OF WHEEL LOAD

Figure 1 - Conceptual Illustration of Mechanisms by which Geotechnical Fabric Improves Road Performance. After Haliburton and Fowler (5).

creep characteristics of the fabric. To increase the useful stress that opposes the wheel load, the amount of deformation should be significant, the tensile strength should be high, the amount of stretch due to tensile strain should be minimal and the material should not creep or relex under strain. This mechanism of reinforcement is commonly referred to as the "membrane effect".

In order to take maximum advantage of the types of reinforcement described above, it is necessary to deform and induce tensile strains within the fabric. This may be done during construction or immediately after the road is open to traffic. The desired method of achieving this type of reinforcement, according to Halliburton and Fowler (2), depends on whether the road is intended to be of temporary use or of a more permanent nature.

For temporary roads the aggregate is placed with minimal compaction and the road is "under designed" so that the first day of traffic rut depths of two to three inches occur. This rutting will deform and induce the required stress in the fabric. The ruts are then filled with more material and compacted. In this way, the greatest thickness of aggregate is placed under the wheel path and future rutting is minimized. For more permanent roads prior rutting can be done by initially placing only a half or two thirds of the intended aggregate of two or three inches. The remaining aggregate is then placed and compacted.

It is important to emphasize that during the procedure to deform the fabric it is essential that the fabric is well anchored so that slippage does not relex the tension induced in the fabric. If the fabric is placed across the entire width of the road and slippage is still a problem then it will be necessary to anchor the fabric by alternative means. As an example the edges of the fabric could be secured to logs or timbers placed along the sides of the road before the aggregate is placed. Alternatively the fabric should be wide enough to avoid slippage which may mean having to build a road wider than necessary. The possible disadvantages to these methods is that once the position of the depressions in the geotextiles have been established, vehicle wheel paths should not be allowed to deviate from them.

It is generally agreed that the reinforcing capability of geotextiles is only fully realized if the subgrade is soft (less than 3% Californian Bearing Ratio test (CBR)). However the amount of aggregate used

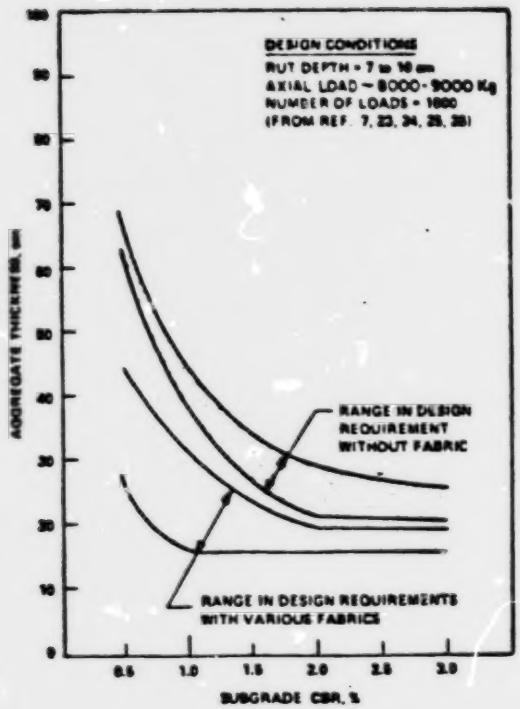
and life of a road can be extended by using a fabric to separate the subgrade from the aggregate. This particular use is effective for much greater subgrade CBR values and is discussed in the next section.

Subgrade Separation

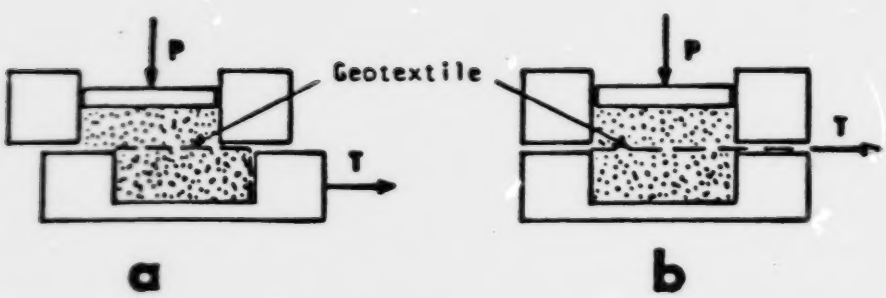
Often roads are designed with an aggregate layer that is thicker than otherwise necessary in order to compensate for the degradation in strength due to the infiltration of the subgrade soil into the base of the aggregate. A small amount of fine grained soil (as little as 5 to 10%) can dramatically affect the critical properties of the aggregate. Using an increased thickness of aggregate to allow for subgrade intrusion obviously increases the cost of the road and may exhaust the local supply of aggregate. By laying a geotextile on the subgrade before laying the aggregate the fine subgrade soil will be prevented from penetrating the aggregate base. This method of construction will also have some influence on preventing other adverse effects of increased fines content in the aggregate layer. These adverse effects include an increase in permanent deformations, moisture sensitivity, frost action behaviour, ballast pumping and a decrease in permeability.

If only subgrade-aggregate separation is considered and reinforcement is not deemed to be necessary then the mechanical requirements are limited to those required for construction and durability. The essential properties of the geotextile are those that will prevent the soil from moving upward into the aggregate either in suspension or by plastic flow. These hydraulic properties will be determined by the pore size and the permeability of the fabric. If movement is by suspension then the pore size of the fabric is crucial. If however, the flow is plastic the pore size necessary to prevent migration is much less critical. There is very little data, as yet, to indicate what permeability is required but it seems reasonable to assume that the initial permeability of the fabric should be at least that of the subgrade. The available evidence has shown that the problem of intermixing of soil in surface haul roads has been eliminated by the use of geotextiles. Consequently, it is not necessary to have a thicker aggregate layer to compensate for subgrade intrusion. It has been reported (2) that a reduction of between 25 to 40% in the thickness of the aggregate

layer can be realized over soft subgrades (less than 3% CBR) as demonstrated on Figure 2.



Typical aggregate thickness requirements for haul roads with and without fabric.



Two types of tests performed using a shear box: (a) Shear test; (b) Pull-out test.

Figure 2

Subgrade Drainage

If the subgrade soil is cohesive and saturated with water the shear strength of the soil is much reduced. This is due to the water that is trapped between the particles. When pressure is applied to the soil the water prevents the particles from consolidating and so prevents the usual increase in strength that occurs when unsaturated soil is compacted. The positioning of a geotextile over the subgrade provides a path for any excess water to drain from the subgrade avoiding a general loss of subgrade support.

Design Criteria of Roads Employing Geotextiles

Rational design criteria for aggregate roads on soft subgrades have been developed on a empirical basis but there is insufficient data to indicate that they are entirely trustworthy. Unfortunately, no comprehensive scheme has yet been developed to adequately model soil-fabric systems and so impirical design methods have to be relied upon. However, manufacturers of geotextiles and government departments concerned with transportation are funding research to improve the realiability of their empirical design guidelines. Examples of these guidelines (3) are reproduced in Appendices A, B and C. Despite the lack of firm design criteria it should be stressed that virtually all of the attempts to build roads using geotextiles over soft subgrades have been largely successful, (3,4,5).

DISCUSSION

The use of geotextiles has no significant benefits for paved roads and it is generally agreed that the application of this method to aggregate roads is unlikely to have any large economic benefit unless the subgrade is very soft, i.e. a CBR of less than 3). Soft subgrades with a CBR of less than 3 do occur within surface mining properties and so the techniques may be of benefit where either strong aggregates are not abundant, or the available aggregate material is of minimal quality, or where it is desirable to conserve or extend the available aggregate resource. For subgrade conditions with a CBR of 1% or less (difficult to walk on) no satisfactory cost-effective alternative except the use of fabric will probably exist.

Another possible benefit of geotextiles that has not been mentioned yet is that they could be of substantial aid in removing the aggregate layer after the useful life of the road has ended. The aggregate can then be used for new road construction and the land can be restored to its original use, such as agriculture.

CONCLUSIONS

There is still very little data to formulate accurate design criteria, but the available information indicates that the use of geotextiles on soft subgrades (a CBR of less than 3%) can reduce the amount of aggregate, necessary to construct a haul road, by as much as 25 to 40%. Subgrades with CBR's of less than 3% do occur on surface mine properties and in these situations the use of geotextiles in the construction of mine haulage roads may well be economically desirable.

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APPENDICES A, B AND C.

AN EXAMPLE OF GUIDELINES FOR THE USE OF GEOTEXTILES IN ROAD CONSTRUCTION

Report No. FHWA-TS-78-205

GUIDELINES FOR USE OF FABRICS IN CONSTRUCTION AND MAINTENANCE OF LOW-VOLUME ROADS

by

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CHAPTER 4: SUBGRADE RESTRAINT

I. INTRODUCTION

Subgrade restraint is the process or concept of preventing or reducing soil movement and soil strain by use of fabrics for confinement. The primary function is: restrain soils (against shear failure at low stresses). The term subgrade restraint is used instead of the term subgrade reinforcement because: a) it better describes the process of the soil and fabric interaction which gives the apparent increase to the soil bearing capacity, and b) to avoid the possible misconception that the fabric itself strengthens a soil. In the Forest Service, the term subgrade reinforcement is normally associated with the addition of pit run rock material to support vehicles.

The subgrade restraint mechanism will predominate only for weak soils loaded (stressed) to levels at which the soil would fail or rut without fabrics. The economics of using fabrics to reduce structural thickness based on the restraint mechanism will control only for subgrades with a CBR less than or equal to 2 or 3. For subgrades with CBR greater than 2 or 3, the separation or filtration function will control.

II. THEORY

The restraint mechanism can best be understood by reviewing bearing capacity factors used for footings:

Soil bearing capacity failures normally occur by rupture (general shear) of soil under and adjacent to footings similar to Figure 4-1a. For loose or soft soils, the failure occurs by punching or rutting which is referred to as "local shear," (12). (Figure 4-1b.)

$$q = \frac{\gamma b}{2} N_\gamma + C N_c + q' N_q \qquad (Eq.\ 4\text{-}1)$$

The term γ is the soil unit weight, the term b is the footing width, C is the soil cohesion, q' is the vertical overburden pressure at the footing level.

The values of N_γ , N_c, and N_q are dimensionless bearing capacity factors that depend only on ϕ and on the shape of the failure zone as assumed by different investigators. Values for these factors as functions of ϕ from the analyses of Terzaghi and Meyerhoff are given in Figure 4-2 (20). ϕ is the angle of internal friction.

For a footing resting on the ground surface and loaded rapidly to failure without permitting drainage, $\phi \geq 0$ and equation 4-1 becomes:

$$q = CN_c \qquad (Eq\ 4\text{-}2)$$

Note: $\phi = 0$ only for saturated low permeable soils under rapid loading such as wheel loads.

The bearing capacity of the footing under this condition depends only on the cohesion of the soil (undrained shear strength) and N_c. N_c from Figure 4-2 for $\phi = 0$ is 5.4 to 5.9 for general shear and 3.8 for local shear.

From laboratory model studies using aggregate and fabric over soft soils, Barenberg (16) concluded that the allowable stress on a soft soil under repeated loading could be predicted from E_q 4-2 using the undrained shear strength of the soil for C and bearing capacity factors, N_c, of 3.3 and 6.0. The values of 3.3 and 6 C are the stress level at which deep rutting (greater than 2 inches) will occur with only a small number of loads when fabric and no fabric respectively are used. N_c values of 5.0 and 2.8 C are proposed by writers to be the stress levels, with and without a fabric layer respectively, to which soft subgrades could be stressed without excessive ruts (less than 2 inches). These values are the same order of magnitude as the "general shear" and "local shear" values for footings.

Barenberg constructed a series of curves similar to Figure 4-2 for determining the thickness of material required to reduce the stresses from the wheel loads to the allowable level when roads were constructed with and without fabric. The factors of 3.3 and 6.0 are incorporated in Figure 4-2. Figures 4-3, 4-4 and 4-5 are a similar set of curves developed for single, dual, and dual tandem wheel loading over a board range of loadings. Boussinesq's equation was used for determining the vertical pressure under a circular load applied at the

ground surface. The factors of 2.8, 3.3, 5 and 6.0 C were not incorporated into these curves to minimize the number of curves and to allow adjustment of the factors as more knowledge is gained.

Barenberg also recommended the use of field vane shear and cone penetration devices for determination of soil strengths. Due to a natural wide variation of soil strength in the field, he recommended taking many groups of readings at several locations on a project. The designs soil strength for a group of readings is the soil strength at which not more than 75% of readings are higher.

III. DESIGN PROCEDURE

Naturally ocurring soils have a wide variation in soil strength (16) and failures can be expected to initiate at the weakest soil area and rapidly progress throughout a wide area. It appears appropriate to determine the undrained strength in the field utilizing rapid means to determine the lower limit of soil strength and to design to prevent failure in the weakest soil unit. Based on these considerations, work by Barenberg and the trial use project at Quinault, Washington, we recommend the following procedure for design of low volume roadways using fabrics for subgrade restraint:

A. Visually segment the road into logical construction segments in the field, taking into consideration soil type, vegetation, road grade, terrain slopes, etc.

B. Determine the soil strength in the field using the cone penitrometer (C approximate equal cone value divided by 10 or 11) and/or vane shear (C is read directly).

C. Make the strength determination at 2 or 3 separate places where the soil appears to be the weakest. Make 6 to 10 strength readings at two depths (0-9 inches and 9-18 inches) at each sample site (sample site is approximately 3 feet in diameter).

D. Determine the design strength as the 75th percentile strength for each set of readings at each depth. The 75th percentile is the strength at which 75 percent of the soil strength readings are higher than this value.

E. Determine the maximum single wheel load, maximum dual wheel load, and the maximum dual tandem wheel load anticipated for the road during the design period.

F. Determine the required aggregate thickness from the load-stress depth curves (Figures 4-3, 4, 5) for each maximum loading. Enter the curve with stresses equal to 2.8, 3.3, 5 and 6.0 times the design strength for each depth at each location.

G. Plot the aggregate thickness for each test location to scale by station on a road profile sheet (plot only the greatest aggregate thickness determined from either the shallow or deep strength readings).

H. Show the field determined road segments on the profile. Connect the plotted 75th percentile aggregate thickness readings with straight lines (2.8, 3.3, 5 and 6.0 C).

1. Select the design thickness and design road segments visually from the plot of the aggregate thicknesses. The design depth and design segments should be to the next highest 1-inch thickness. The strengths and aggregate thicknesses can aid in the selection of design road segments.

The significance of the thicknesses determined from the charts using various values of C are:

2.8C is the stress level on the subgrade at which very little rutting will occur under a great amount of traffic (greater than 1000 18K axle equivalencies) without fabric.

3.3 C is the stress level at which a great amount of rutting will occur under a small number of axle loadings (probably less than 100 18K axle equivalencies), without fabric.

5.0 C is the stress level at which very little rutting would be expected to occur at high traffic volumes (greater than 1000 18K equivalency axles) using fabric.

6.0 C is the stress level at which a great amount of rutting will occur under a small number of axle loadings (probably less than 100 18K axle equivalencies) using fabric. A great amount of rutting is considered to be a 4-inch or greater rut. Very little rutting is considered to be less than 2 inches of rutting extending into the subgrade.

Other important points to remember are:

A. If more rutting occurs during construction than was designed for, the thickness should be increased at least as much as the thickness difference between 2.8 C and 3.3 C.

B. Surface deflections at stress levels of 3.3 C without fabric and 6.0 C with fabric will be equal.

C. Roads on very soft soils are usually weakest at the time of construction. The subgrade will tend to gain some strength with time due to consolidation under fill weight and traffic. Subgrade contamination of the fill will be very minor when fabrics are used.

D. The maximum fabric potential and thus the maximum economy is achieved on low standard roads where high deflections and 4- to 6-inch ruts can be tolerated. Design values of 6.0 and 3.3 C, with and without fabric, can be used.

E. If poor quality fill materials are used, the thickness of good quality base and surfacing required to prevent rutting of the poorer material must be designed using standard design methods (15).

F. Fabrics should not be used for subgrade restraint when soil CBR is greater than or equal to ($\geq$)3 (vane shear cohesion 1500 psf and cone penetrometer $\geq$ 120 psi). (CBR-vane-cone relationships can be approximated using Figure 4-2.)

G. Preliminary test results from the Quinault "Trial Use" installation showed that the lightweight non-woven fabrics (4 oz per square yard) performed as well as the heavier (8 to 16 oz per square yard) once they were installed.

H. The above design procedure is applicable only to shallow deposits of soft materials. For deeper deposits settlement of the fill must also be considered. See Vischer (32), and Greenway and Bell (33).

Figure 4-6 is the Special Project Specification being used on several projects in Region 6. The specification is necessarily non-restrictive to determine, through monitoring of these installations, the optimum design specification and construction of these installations.

Minimum fabric strength properties specified in current "Special Use" specifications are:

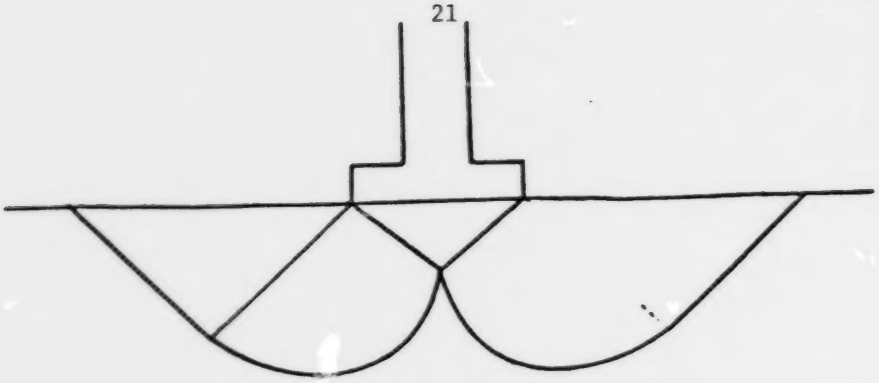
A. Grab Test, ASTM D-1682 warp and fill (lb/in) = 120 minimum.

B. Weight, (oz/yd^2) = 4.0 minimum.

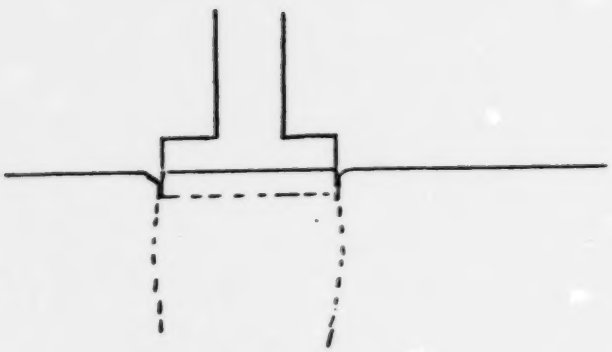
C. Elongation at failure = 50% minimum.

IV. QUINAULT NON-WOVEN FABRIC TRIAL-USE INSTALLATION

Background: One of the major uses of non-woven fabric is subgrade restraint where road construction must cross areas of low bearing strength (CBR $<$ 3). Generally, areas with a high water table fall in this category, especially when combined with organic and/or fine-grained soils. Peats and muskegs would be good examples of



a) Failure by general shear



b) Failure by local shear

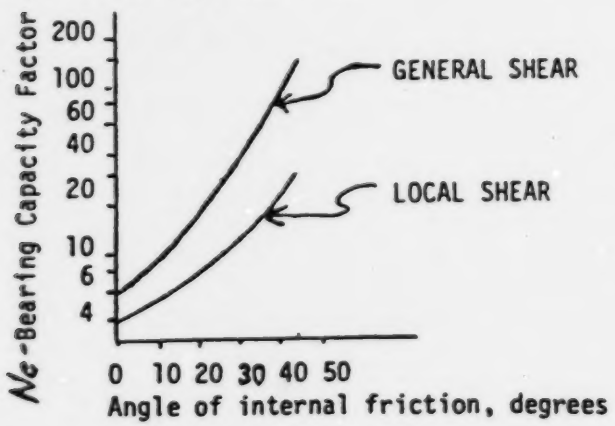


Figure 4-1 - Types of foundation shear failure.

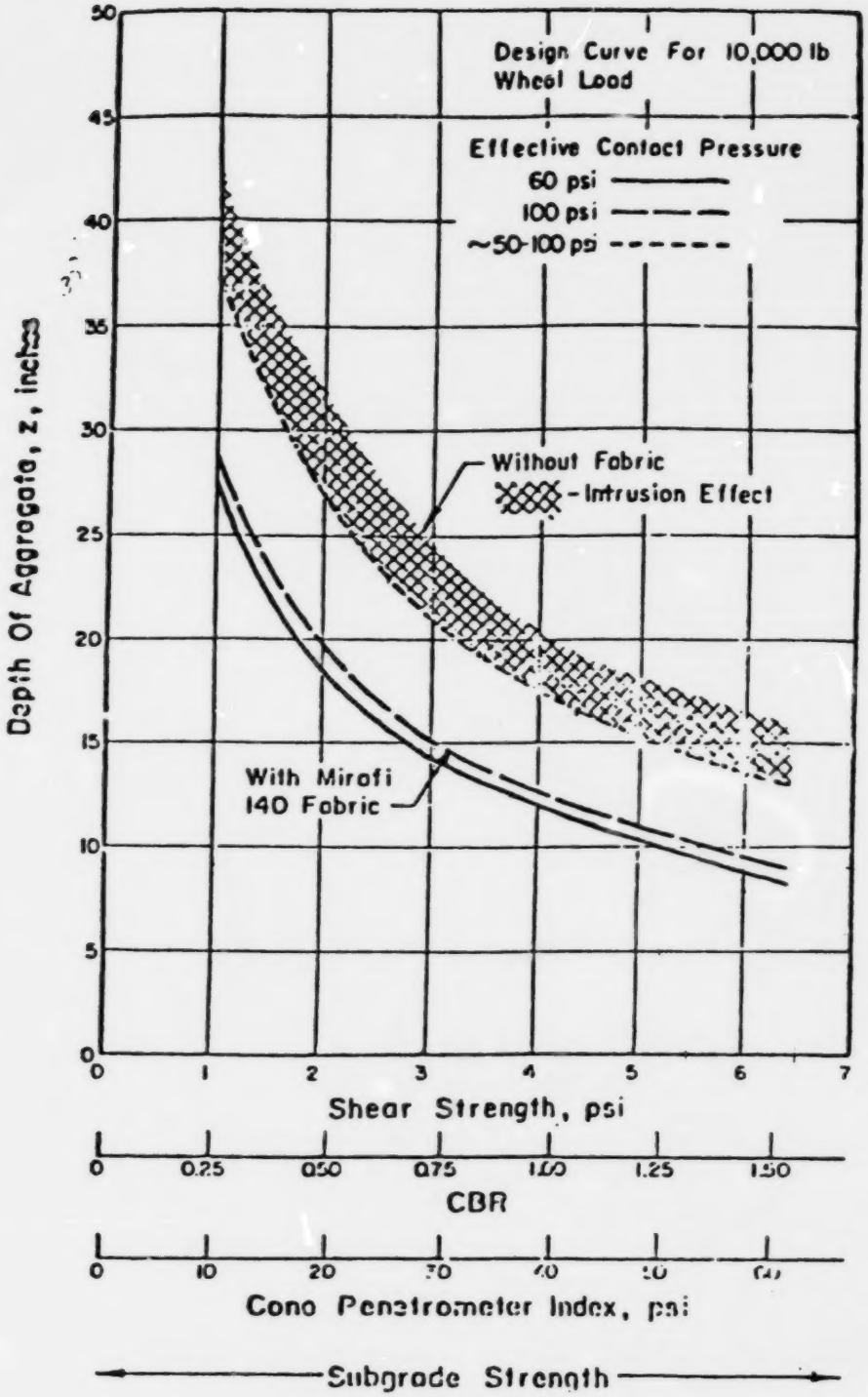


FIGURE 4-2

Thickness Design Curve For 10,000 lb. Wheel Load

(from Barenburg, (16))

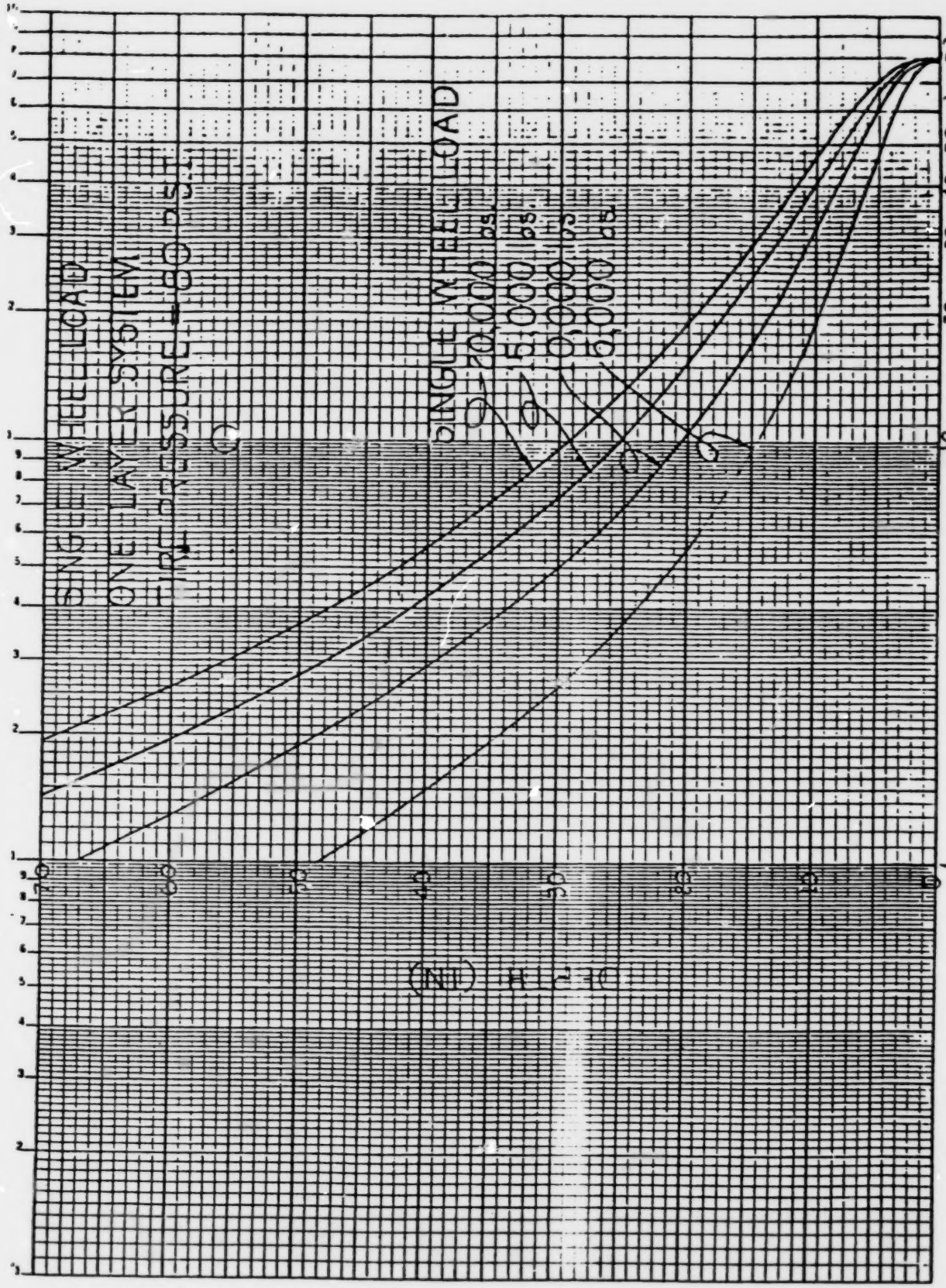

SINGLE WHEEL LOAD
ONE LAYER SYSTEM
TIRE PRESSURE 80 psi
SINGLE WHEEL LOAD
10,000 lbs
15,000 lbs
20,000 lbs
CNc, P.S.I.

FIGURE 4-3

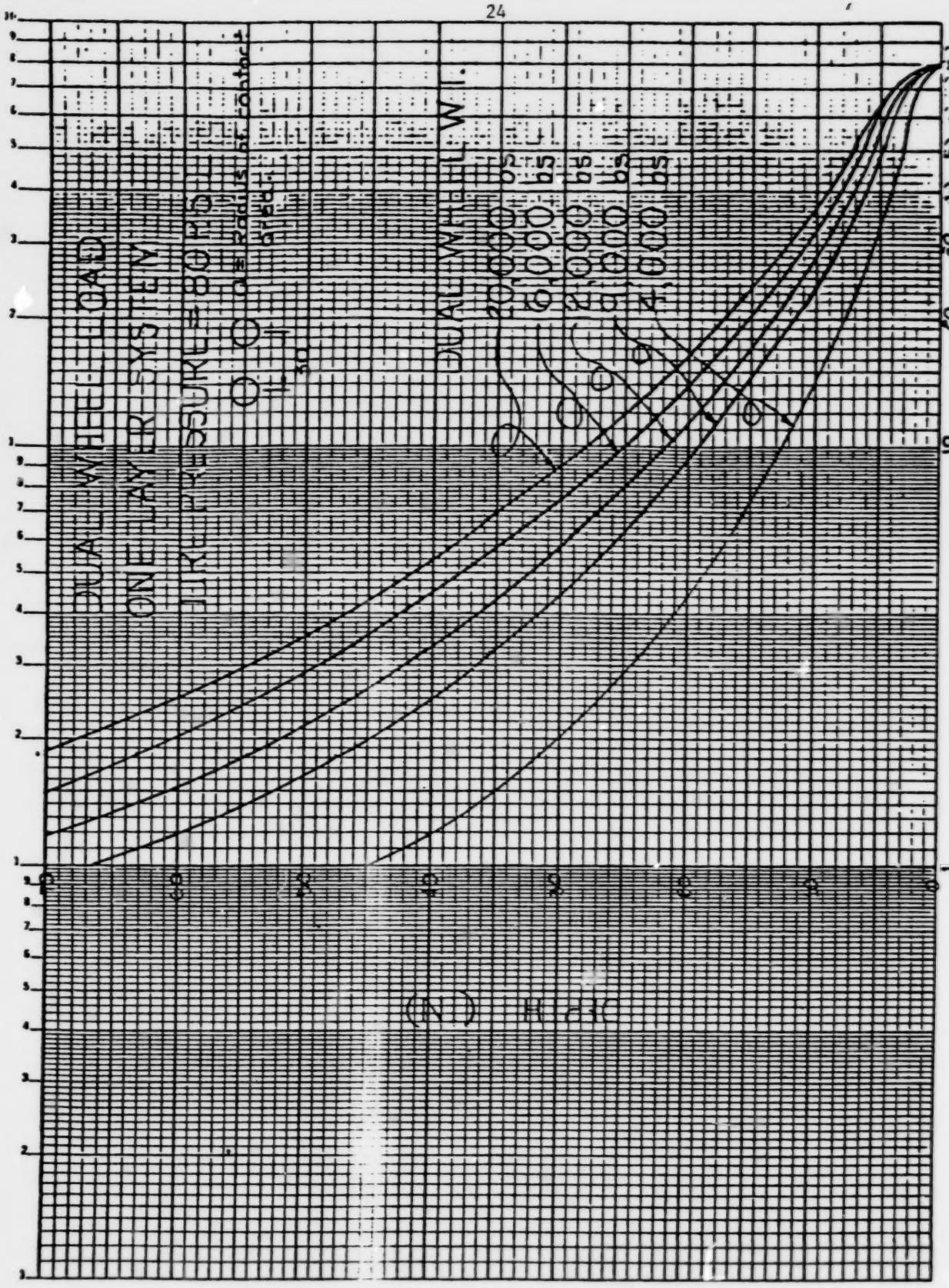

RATIO WHEEL LOAD
ON EACH SKID
TO
TOTAL WHEEL LOAD
ON ALL SKIDS
$\frac{W}{W_T}$
$\frac{W}{W_T} = 0.25$
$\frac{W}{W_T} = 0.20$
$\frac{W}{W_T} = 0.15$
$\frac{W}{W_T} = 0.10$
$\frac{W}{W_T} = 0.05$
$C N_c$, P.S.I.
(N.D) Width

FIGURE 4-4

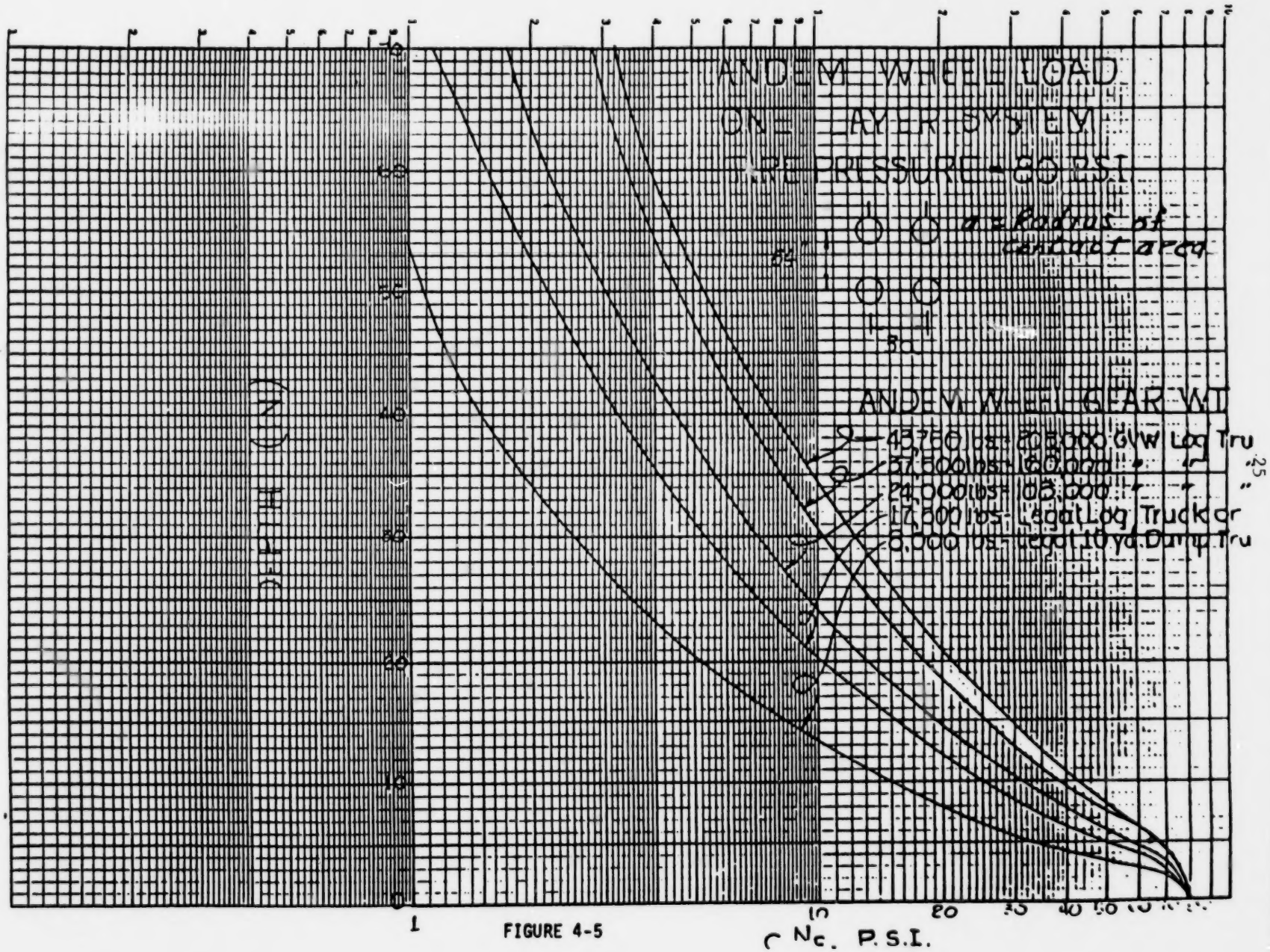

ANDEM WHEEL LOAD
ON LAYER SYSTEM
TIRE PRESSURE = 80 PSI
a = Radius of
Contact area
ANDEM WHEEL GEAR WT
43,760 lbs: 20,000 GVW Log Tru
57,500 lbs: 60,000 " " "
24,000 lbs: 65,000 " " "
17,500 lbs: Legal Log Truck or
8,000 lbs: Legal 10 yd. Dump Tru
25"
Z (FT.)
C Nc. P.S.I.

FIGURE 4-5

Appendix B

NICOLON CORPORATION CRITERIA FOR THE DESIGN OF GEOLON FABRIC-REINFORCED UNSURFACED ROADS

A High-Performance Fabric Reinforcement Design Criteria

Developed

for

Nicolon Corporation
Norcross/Atlanta, Georgia

by

Haliburton Associates
Engineering Consultants
Stillwater, Oklahoma

July, 1981

The opinions, findings, and conclusions contained herein are those of Haliburton Associates, and not necessarily those of Nicolon Corporation

NICOLON CORPORATION CRITERIA FOR THE DESIGN OF GEOLON FABRIC-REINFORCED UNSURFACED ROADS

INTRODUCTION

Geotechnical fabrics have been used, for many years, to improve the performance of unsurfaced roads constructed on soft ground (subgrade). The permeable fabric provided separation between soft cohesive subgrades and cohesionless sand/gravel/crushed stone cover material placed over the fabric, and restrained the soft subgrade from immediate rutting failure. As a result, the total thickness of aggregate required in road construction could be reduced, compared to the thickness needed for satisfactory performance without fabric. In general, prior road design criteria were developed for low-strength, low-tensile-modulus, nonwoven and slit-film tape fabrics.

Nicolon Corporation manufactures a broad spectrum of high-tensile-strength, high-tensile-modulus fabrics for use in soil reinforcement. Availability of such high-performance fabrics made it possible for Nicolon to develop an unsurfaced road design criteria based on fabric reinforcement, in addition to subgrade restraint and material separation. Further, consideration has been given to fabric survivability requirements during placement and fabric workability requirements to insure rapid field placement, concepts ignored in other fabric-related road design criteria.

The Nicolon unsurfaced road design criteria described herein were developed by Haliburton Associates, Stillwater, Oklahoma, under the direction of Dr. T. Allan Haliburton, P.E. Criteria were developed from laboratory model tests and analytic determinations, and verified by evaluation of various high-performance fabric field case histories. The Nicolon criteria provide guidelines for road construction with considerably less cover material thickness than required by other available low-strength fabric design criteria, and also allow selection of the proper Nicolon fabric to give necessary fabric survivability and field workability. General fabric-reinforced road construction procedures are also presented, to provide guidelines for establishing construction specifications.

BASIS FOR NICOLON DESIGN CRITERIA

The Nicolon criteria are based on three factors not considered by other fabric road design criteria: fabric-reinforced soil behavior, fabric survivability during placement, and fabric field workability to speed field construction operations. The criteria also consider the subgrade restraint and material separation concepts upon which other low-strength fabric design criteria are based.

Fabric Reinforcement

Optimum fabric reinforcement of cohesionless soil placed above the fabric is primarily related to the width of tire carrying the largest wheel load expected for the roadway. Thus, the Nicolon road design criteria have a constant fabric cover material thickness, independent of subgrade strength. By placing fabric at this "optimum" depth, maximum reinforcement potential is obtained. Placing additional cover material does not give an additional factor of safety, but instead reduces the in-service performance of the system.

Fabric Survivability

No fabric can perform any function unless it survives placement and covering with roadway material. Nicolon high-performance fabrics have the ability to survive when placed directly on rough terrain, with a minimum of expensive site preparation. Other fabric road design criteria do not consider this factor, of prime importance in successful field construction, forcing the contractor to conduct extensive site preparation in order to assure survival of low-strength fabrics.

Fabric Field Workability

The key operation in fabric-reinforced road construction is fabric placement. On very soft soils, the rate at which fabric can be placed is related to its ability to support the contractor's workmen without soil cover and its ability to support the contractor's equipment during

material covering operations. High-performance Nicolon fabrics possess excellent field workability, allowing rapid project construction on even the softest soil conditions. Other fabric road design criteria do not consider this factor, giving no guidance on fabric selection to expedite construction and thus reduce construction cost.

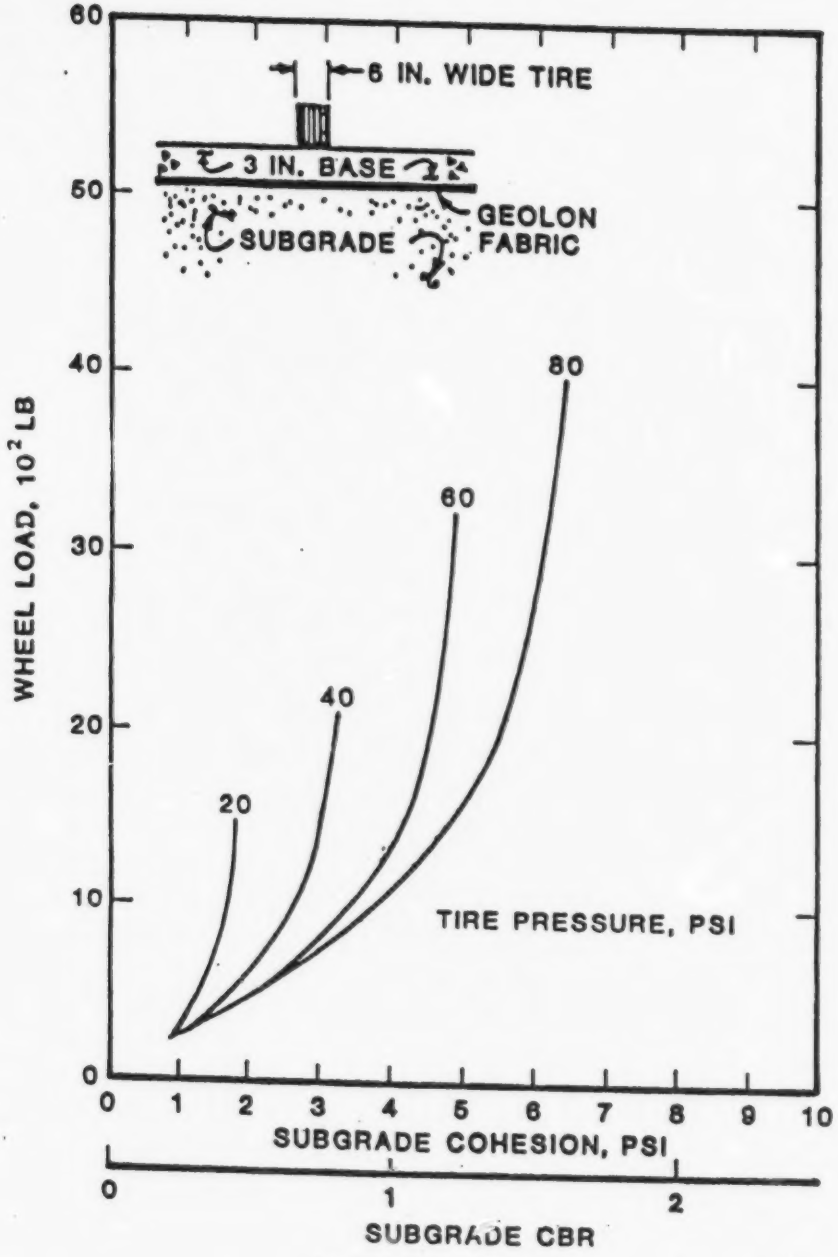
USE OF NICOLON DESIGN CRITERIA IN SELECTION OF APPROPRIATE GEOLON FABRIC

Nicolon fabrics used in the design criteria include Geolon 200, 400, 600, 700, and 1250. Performance properties increase with increasing fabric designation, i.e., Geolon 600 is a higher performance fabric than Geolon 400. Use of the design criteria will indicate which Nicolon fabrics are suitable for the exact site-specific conditions of the project, considering in-service road performance, fabric surival during placement, and optimum rate of road construction. Of the fabric choices obtained from each of the Nicolon design criteria, the lowest-numbered Nicolon fabric will usually be the most cost-effective choice. An additional margin of safety may be provided by using a higher numbered Geolon fabric than actually necessary, if desired.

Design Curves for Selecting Road Thickness and Allowable Loading

Figures 1 through 3 show design curves for vehicles with single tire widths varying from 6 in. to 36 in., and Figure 4 shows curves for a standard dual-wheel configuration and a standard tandem-axle configuration. The optimum depth of well-compacted cohesionless, nonplastic cover material for the given tire and wheel configuration is shown on each Figure.

The one variable in site-specific road design which cannot be changed is subgrade strength. For the Nicolon design criteria, subgrade strength must be known in terms of its field California Bearing Ratio (CBR) or undrained soil cohesion c. Once subgrade strength is determined, the design curves are used as follows:



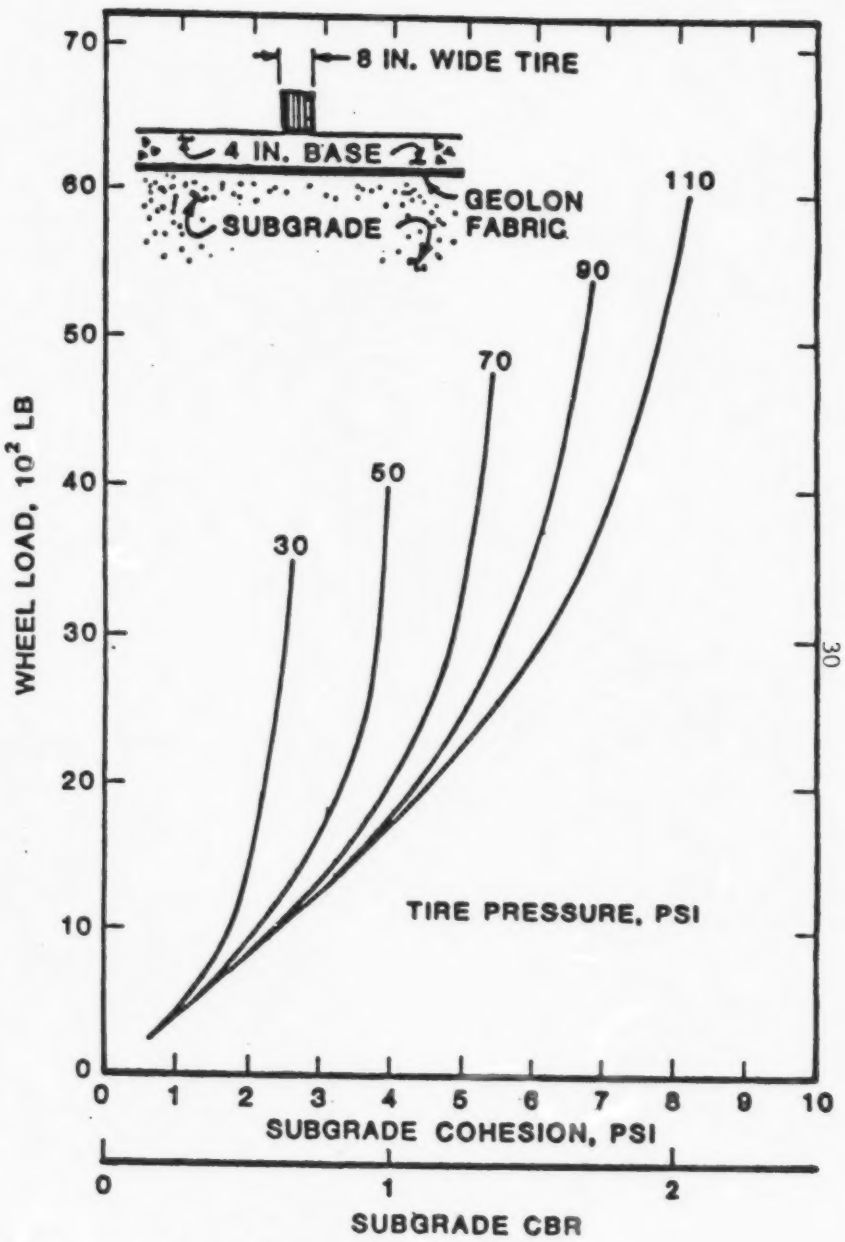
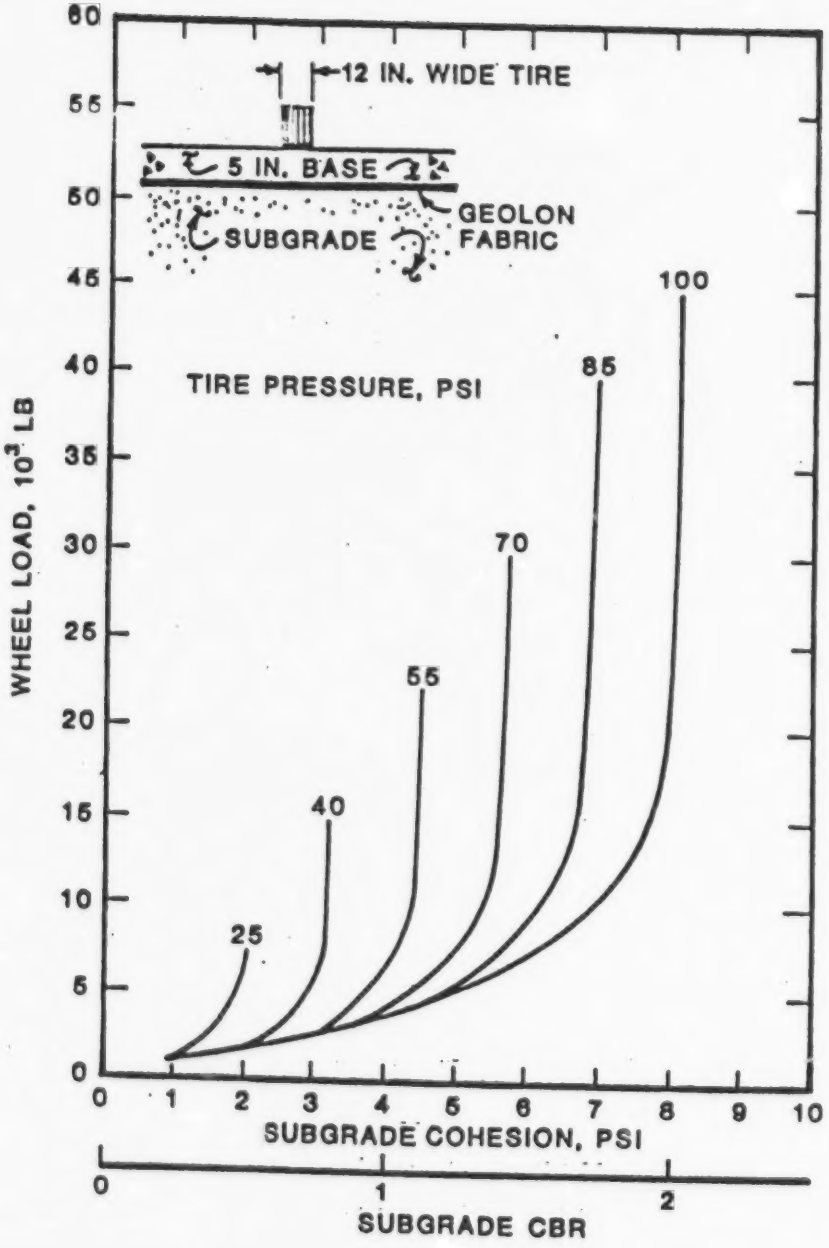


Figure 1. Design curves for vehicles with 6-in.- and 8-in.-wide tires.



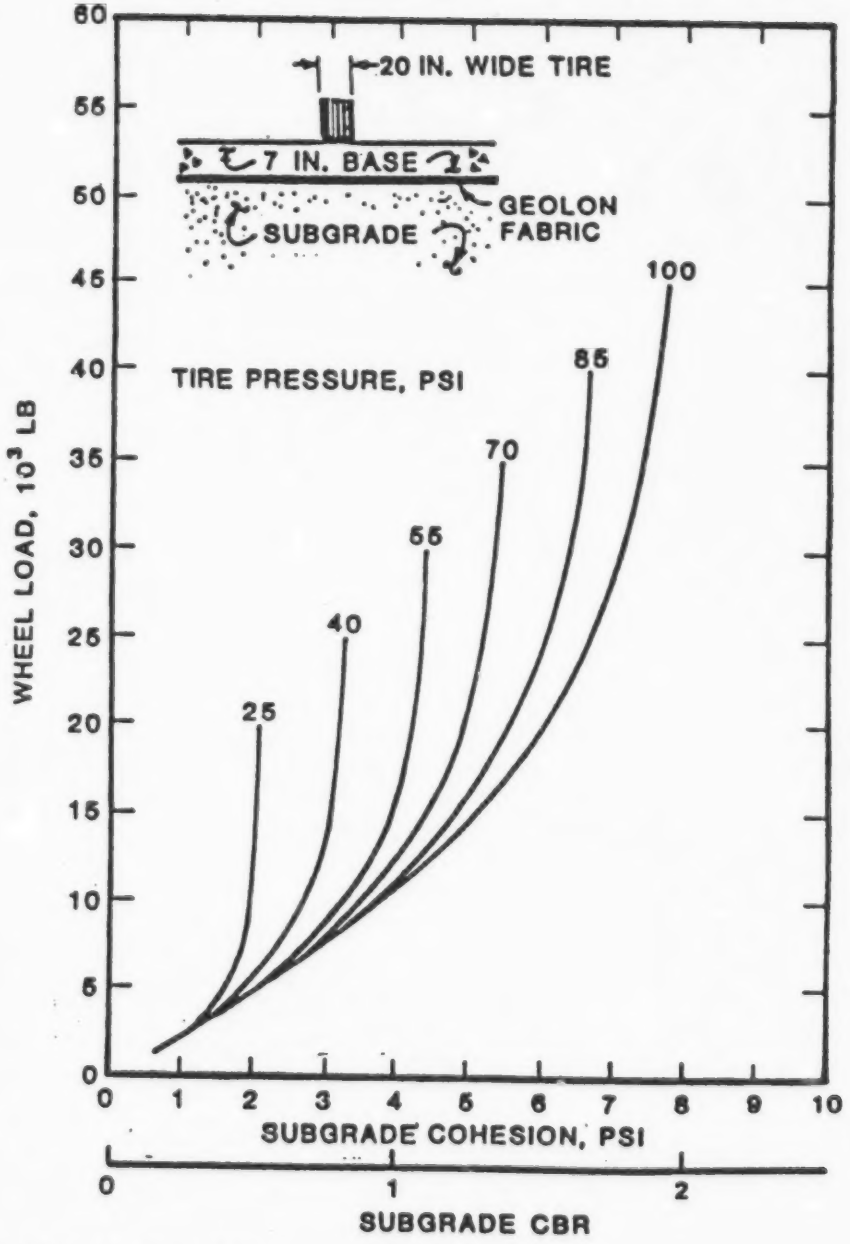
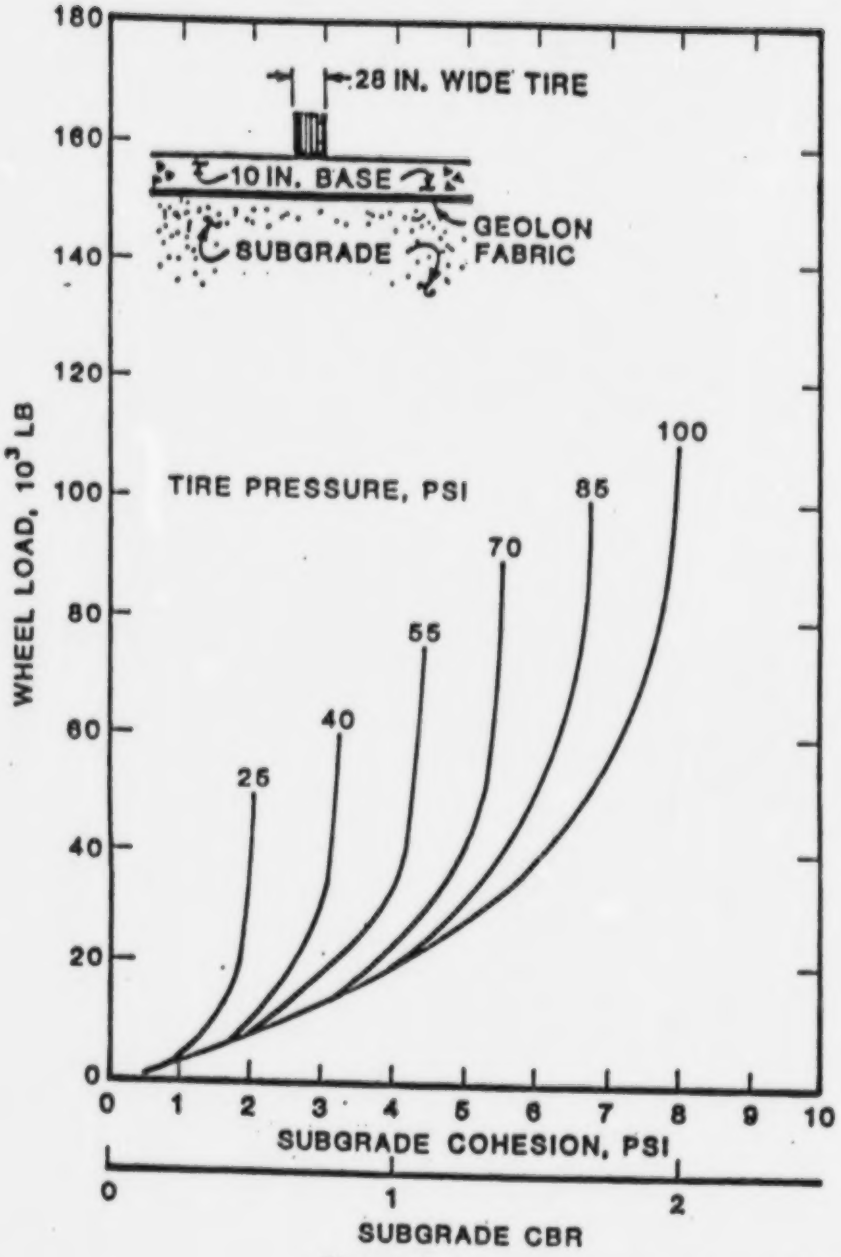


Figure 2. Design curves for vehicles with 12-in.- and 20-in.-wide tires.



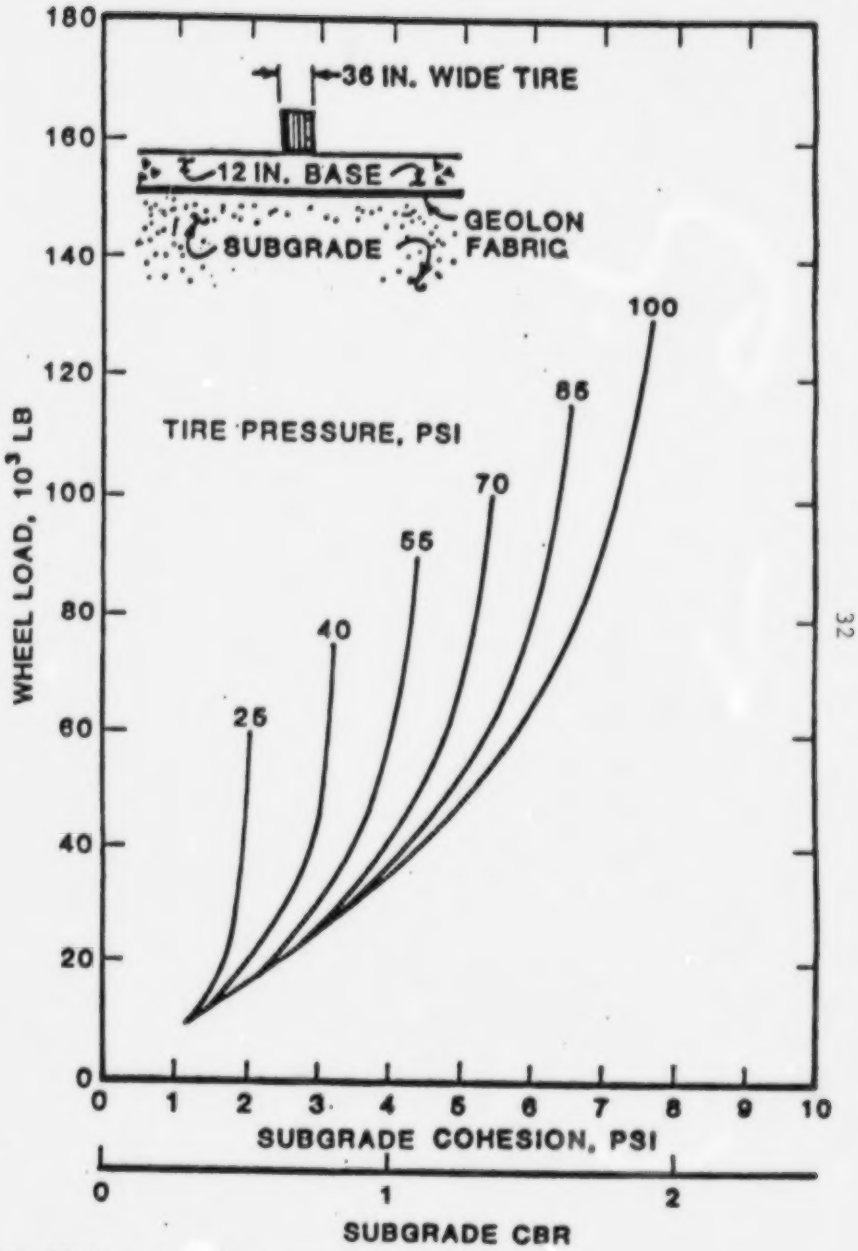


Figure 3. Design curves for vehicles with 28-in.- and 36-in.-wide tires.

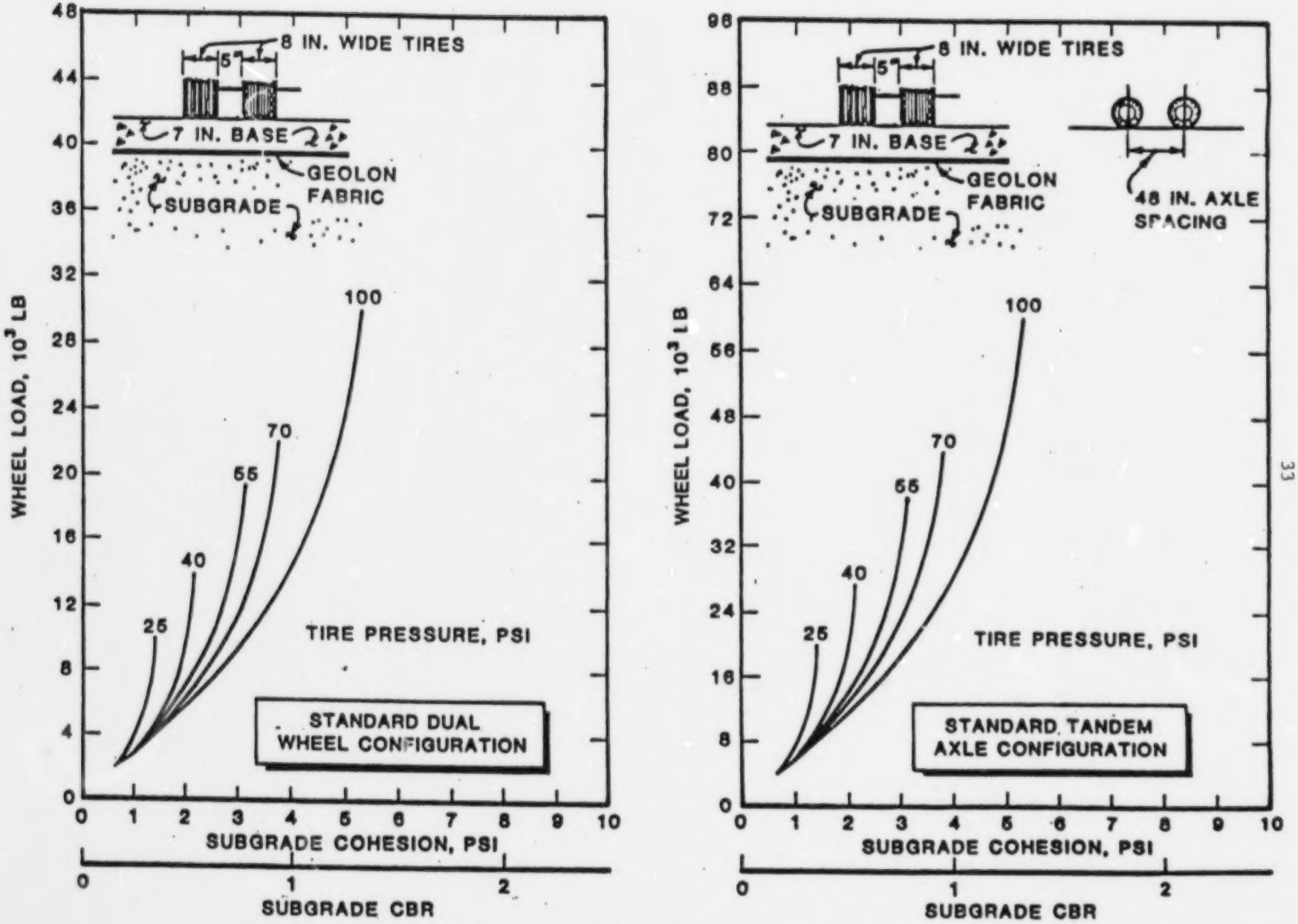


Figure 4. Design curves for standard dual-wheel and tandem-axle tire configurations.

a. Determine the appropriate design curve to use, based on the tire width of the vehicle having the greatest wheel load to be carried by the roadway. If the vehicle has a tire size not given in Figures 1, 2, or 3, interpolate between curves.
b. Locate the existing subgrade strength on the horizontal axis of the appropriate curve, and extend a vertical line from the subgrade strength value.
c. Locate the design maximum wheel load on the vertical axis of the appropriate curve, and extend a horizontal line from the design wheel load value.
d. At the intersection point of the vertical and horizontal lines produced in Steps b. and c., determine the maximum allowable tire inflation pressure for the design vehicle. If the maximum allowable tire pressure is greater than the actual tire pressure anticipated for the design vehicle tires, satisfactory in-service performance should be obtained. The required cover material thickness is shown on the appropriate design curve.
e. If the maximum allowable tire inflation pressure from the appropriate curve is less than the expected tire pressure of the design vehicle, it will be necessary to reduce the vehicle loading or use wider tires to obtain satisfactory in-service performance. However, with the possible exception of unusually high loads on very soft subgrades, the design curves should indicate successful performance for all commercially available vehicles.

The following items should be noted concerning use of the Nicolon in-service performance criteria curves:

a. Cohesionless, nonplastic material, such as sand, gravel, shell, or crushed stone, must be placed over the fabric. Silt and/or clay-type soils cannot be used.
b. If sand is used as a cover material, it may be desirable to place a 2 in.$\pm$ surfacing of shell, crushed stone, etc., to provide resistance to road surface tire abrasion.

c. Road thickness requirements given on the appropriate design curve are for well-compacted cohesionless material, compacted by pneumatic roller. If cover material is to be compacted by tires and tracks of construction equipment, cover thickness should be increased by 15%. If cover material is to be placed in an essentially uncompacted state and compacted by road traffic, cover thickness should be increased by 25%.

d. If cover material is well-compacted, in-service rutting should not exceed 3-in. depth. If left uncompacted or semi-compacted, 3 in. or more rutting may occur (depending on total road thickness) as traffic compacts the cover material. Rutting should occur under the first-day traffic. Rutting should be repaired by filling the ruts with new cover material. After initial rutting is repaired, minimal future in-service rutting should be expected. Material needed to fill the ruts should not be taken from the center and edges of the roadway, else fabric anchorage will be reduced.

After determining the design road thickness and insuring that adequate in-service performance can be obtained, the appropriate Nicolon Geolon fabric can be selected.

Fabric Selection for Field Survivability

Tables 1 and 2 relate existing site conditions, degree of contractor site preparation, type of fabric cover material to be used, and type of construction equipment to the performance properties of Nicolon Geolon fabrics. From Table 1, determine the suitable Geolon fabrics, based on existing site conditions and the amount of site preparation necessary or anticipated. As may be noted in Table 1, more contractor site preparation reduces the fabric performance requirements. However, it is usually more cost-effective to minimize site preparation and use a higher-performance Nicolon Geolon fabric.

From Table 2, determine the suitable Geolon fabrics based on type of fabric cover material and type of construction equipment to be used.

TABLE 1. GEOLON FABRIC SELECTION BASED ON FABRIC SURVIVABILITY AS A FUNCTION OF SUBGRADE CONDITIONS AND CONSTRUCTION EQUIPMENT GROUND PRESSURE

Subgrade (Soil Surface) Conditions	Construction Equipment	
	Low Ground Pressure ($\leq$ 3.0 psi)	Medium Ground Pressure (3.0 psi-6.0 psi)
Subgrade has been cleared of all obstacles except grass, weeds, leaves, and fine wood debris. Surface is smooth and level such that any shallow depressions and humps do not exceed 6-in. depth or height. All larger depressions are filled. Alternatively, a smooth working table may be constructed.	Geolon 200, 400, 600, 700, 1250	Geolon 200, 400 600, 700, 1250
Subgrade has been cleared of obstacles larger than small- to moderate-sized tree limbs and rocks. Tree trunks and stumps should be removed or covered with a partial working table. Depressions and humps should not exceed 12-in. depth or height. Larger depressions should be filled. Alternatively, a rough working table may be constructed.	Geolon 400, 600, 700, 1250	Geolon 600, 700 1250
Minimal site preparation is required. Trees may be felled, delimbed, and left in place. Stumps should be cut to project not more than 6 in.$\pm$ above subgrade. Fabric may be draped directly over tree trunks, stumps, large depressions, and humps. Holes, stream channels, and large boulders should be filled or removed only if placing the fabric and cover material over them will distort the finished road surface.	Geolon 600, 700, 1250	Geolon 600, 1250

TABLE 2. GEOLON FABRIC SELECTION BASED ON FABRIC SURVIVABILITY AS A FUNCTION OF COVER MATERIAL AND CONSTRUCTION EQUIPMENT GROUND PRESSURE

Cover Material	Construction Equipment	
	Low Ground Pressure ($\leq$ 3.0 psi)	Medium Ground Pressure (3.0 psi-6.0 psi)
Fine sand to medium gravel, rounded to sub-angular	Geolon 200,400, 600, 700, 1250	Geolon 200, 400, 600, 700, 1250
Aggregate up to 2.5-in. size, may be angular	Geolon 200, 400 600, 700, 1250	Geolon 400, 600, 700, 1250
Some or most aggregate larger than 2.5-in. size, angular and sharp-edged, few fines	Geolon 400, 600 700, 1250	Geolon 600, 700, 1250

Fabric Selection for Field Workability

Table 3 relates existing subgrade strength and type of construction equipment to the field workability properties of Nicolon Geolon fabrics. From the Table, determine the suitable Geolon fabrics which will allow rapid construction of the roadway for the given subgrade conditions and construction equipment.

Final Geolon Fabric Selection

The minimum acceptable Geolon fabric for the specific project is selected as follows:

a. Tabulate the lowest-numbered Geolon fabric obtained from each of Tables 1, 2, and 3.
b. Select the highest-numbered Geolon fabric from the three fabrics listed in Step a.

The fabric selected in Step b. is the Geolon fabric with minimum performance properties required for the given project. That Geolon fabric, or a higher-numbered Geolon fabric, should be used to build the project.

RECOMMENDED ROAD CONSTRUCTION PROCEDURES

As benefits of fabric reinforcement are most evident in locations where soft subgrades exist, it is necessary to use low- or medium-ground-pressure construction equipment, to provide proper equipment mobility. Small (5 cu yd) dump trucks are desirable for placement of cover material because of their low weight, but larger tandem-axle trucks may be used if the actual volume of transported material is reduced below struck capacity, to reduce the weight. Cover material spreading may be best performed when low-ground-pressure (2.5 psi to 3 psi) dozers or front-end loaders are used.

Site preparation requirements may range from no necessary site preparation to extensive preparation requirements, which may include

TABLE 3. GEOLON FABRIC SELECTION BASED ON FABRIC FIELD WORKABILITY

Subgrade CBR	Vegetative Cover on Soil Surface	Fabrics Meeting Workability Requirements
< 1.0	All Cases	Geolon 600, 700, 1250
1.0-2.0	Poor Root Mat	Geolon 400, 600, 700, 1250
	Good Root Mat	Geolon 200, 400, 600, 700 1250
> 2.0	All Cases	Geolon 200, 400, 600, 700 1250

removing trees, stumps, and boulders, filling localized depressions, or preparing a roughly or smoothly graded working table. Required site preparation procedures will be controlled by specific site characteristics and fabric performance properties (Table 1).

When fabric is placed, the warp or machine direction should be placed parallel with the road alignment. If two or more parallel strips are required, they should be sewn together, else slippage may occur under traffic loadings. Adjacent roll ends should either be sewn together or overlapped 5 ft. Sewed seams should be at least as strong as the fabric. Large depressions, ditches, shallow creek channels, etc., which will require a reasonable amount of fill to obtain design grade, should have fabric unrolled along the alignment over the existing ground surface, and fill should be placed on the fabric to the approximate ground elevation adjacent to either side of the depression. This fill should then be covered by the layer of fabric used for roadway construction. When this method is used, the underlying fabric layer should be taken back some 6 to 8 ft along the existing grade elevation on either side of the depression to obtain proper fabric anchorage.

Following fabric placement, cover material should be brought to the working face by dump trucks, and the material should be spread with low-ground-pressure dozers or front-end loaders. A minimum 4-in. thickness of uncompacted cover material should be maintained between the tires/tracks of low-ground-pressure construction equipment and the fabric, with 2-in. additional thickness added for medium-ground-pressure equiment. In no case should lift thicknesses be less than twice the maximum size aggregate in the cover material.

Following placement, the cover material may be compacted by construction equipment or initial roadway trafficking. Alternatively, conventional compaction operations by pneumatic roller may be undertaken after the cover material is spread and prior to opening the roadway to traffic. In no case should sheepsfoot rollers be used for compaction, as feet may puncture fabric during initial coverages, and also because compaction with sheepsfoot rollers is inefficient for cohesinless cover materials. If adequate compaction is not carried out prior to roadway use, compaction of the cover material should be expected under initial trafficking, and provisions should be made to fill the ruts with

additional cover material and relevel the roadway shortly after it is placed in service.

COMPARISON OF NICOLON FABRIC DESIGN CRITERIA WITH ALTERNATIVE DESIGN METHODS

In order to illustrate the advantages of the Nicolon high-performance fabric reinforcement road design criteria, as opposed to commonly used low-strength fabric-reinforced road design methods, a comparative design evaluation was made. The Nicolon criteria was compared to:

a. The DuPont design criteria for Typar 3401 fabric,

b. The Celanese design criteria for Mirafi 500X fabric, and

c. The U. S. Forest Service design criteria for nonwoven fabrics.

Table 4 contains necessary cover material thicknesses calculated for a CBR = 1 subgrade and 10,000-, 15,000-, and 20,000-lb dual wheel loads. Along with the design thickness requirements for Geolon fabric, the maximum allowable tire inflation pressure at the given wheel load is also stated.

Table 4 clearly demonstrates the advantages of using Geolon high-performance fabrics. At the example wheel loads of 10,000, 15,000, and 20,000 lb, the Nicolon fabric criteria require less aggregate than any of the three low-strength fabric alternatives. Among the various fabric design criteria, aggregate savings of 3 in. to 14 in. are obtained with the Nicolon design criteria. Savings from use of the Nicolon criteria increase with increasing wheel loads and decreasing subgrade strength.

While Table 4 demonstrates the aggregate saving potential of high-performance Geolon fabrics, it should also be remembered that only the Nicolon design criteria consider the requirements of fabric field survivability and field workability, and only Nicolon offers a wide variety of high-performance fabrics, tailored to fit actual site-specific conditions.

Using the previously presented design criteria to design fabric-reinforced roads offers the distinct advantage of achieving a design which is based on the most recent advances in the use of engineering fabric, and the Nicolon road design criteria for Geolon fabric may be considered the current state-of-the-art.

TABLE 4. COMPARISON OF COVER MATERIAL DESIGN THICKNESSES OBTAINED FROM NICOLON AND ALTERNATIVE DESIGN CRITERIA[1]

Wheel Load (lb)	DuPont[2] Criteria Thickness (in.)	Celanese[3] Criteria Thickness (in.)	U.S. Forest Service[4] Criteria Thickness (in.)	U.S. Forest Service[4] No-Fabric Criteria Thickness (in.)	Nicolon Criteria Thickness (in.)
10,000	14	10	12	19	7 (maximum tire pressure = 110 psi)
15,000	18	13	15	23	7 (maximum tire pressure = 90 psi)
20,000	21	14	17	26	7 (maximum tire pressure = 85 psi)

1 Thicknesses are calculated for road construction on CBR 1 subgrade, with loading from a standard dual wheel configuration.

2 "DuPont Typar Support Fabric for the Construction Industry," Brochure No. E-16754, January, 1978, E. I. DuPont Company, Wilmington, DL.

3 "Mirafi 500X Fabric, Design Guidelines: Haul Roads and Area Stabilization," Brochure No. MTB-1, January, 1979, Celanese Fibers Marketing Company, New York, NY.

4 "Guidelines for Use of Fabrics in Construction and Maintenance of Low-Volume Roads," by J. Steward, R. Williamson, and J. Mohney, Report No. FHWA-TS-78-205, U. S. Forest Service, Pacific Northwest Region, Portland, OR, June, 1977.

A Method for Constructing Aggregate Bases Using TYPAR® Spunbonded Polypropylene

Table of Contents

	PAGE
Introduction	2
The Function of "Typar"	3
Site Survey	4
CBR Determination	5
Traffic Survey (Wheel Loads)	8, 9
Final Design	9
Construction	10
Appendices	
A (Characteristics of Soils Pertinent to Road Foundations)	11
B (Laboratory Identification Procedure)	12
C (Field Procedure for Running California Bearing Ratio (CBR)	13
Glossary	14

Introduction

This is a method used to design and construct aggregate bases utilizing Typar® spunbonded polypropylene as a support membrane. These bases serve as a support medium for numerous dynamic loads in such places as low volume roads, construction haul roads, logging roads, airport runways, sports facilities, parking lots, railroads, and log storage yards. The essential details of design and construction are covered; The Function of "Typar", Site Survey, CBR Determination, Traffic Survey (wheel loads), Final Design, and Construction.

This method uses California Bearing Ratio (CBR) as a basis. It was originally developed by the California Division of State Highways in 1928 and 1929, and selected at the beginning of World War II by the Corps of Engineers for use in the design of flexible pavements.[1] The CBR method, a form of shear test, of flexible pavement design has been widely used both in the United States by State Highway Departments and abroad. In 1953, it was reported that 18 state highway departments were using the CBR procedures.[2] The CBR method has been criticized down through the years for its simplicity and empirical origins. The method detailed herein is open to the same criticism. There is little doubt that further refinement can and will be made. This method is merely one satisfactory way of determining the final aggregate depth. Discussion is confined to construction of aggregate bases on fine grained soils of <15 CBR.

[1] "Development of CBR Flexible Pavement Design Method of Airfields" Amer. Soc. of Civil Eng. Transactions, Paper 2406, Volume 115, 1950.

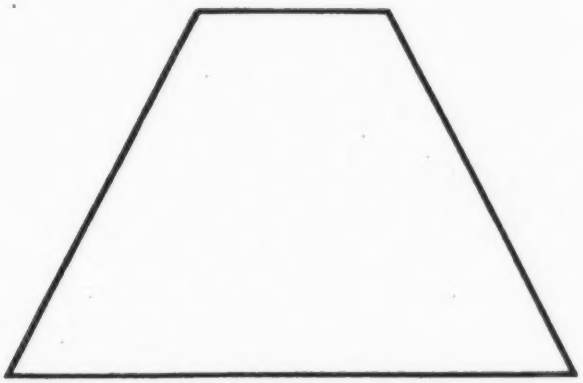
[2] "Flexible Pavement Design" Symposium, Highway Research Board, Bulletin 80, 1953.

The Function of "Typar"

The function of "Typar" under an aggregate base can be summarized in two words:

SEPARATION
SUPPORT (REINFORCEMENT)

The function of an aggregate base is to spread a concentrated load over a wider area. By spreading these loads over a wider area, the loads can be carried over soils that otherwise wouldn't be able to carry them. Picture a pyramid with sides 62.5° to the horizontal.



The wheel load at the top of the pyramid say is 100 pressure units. The load is transferred to the base of the pyramid, thus spreading the load over a wider area resulting in a pressure of say 2 pressure units at the base. Experiments and practical installations have shown that by the addition of "Typar" to the base of this pyramid, the base will be up to **30% more effective.** This feature gives the option of either reducing the thickness of aggregate or utilizing this load bearing capacity as insurance, thus providing longer service life or protection against overloads. Satisfactory functionality of the aggregate demands that the sides of the load bearing pyramid not bulge in use nor should the walls of the pyramid become more vertical. "Typar" prevents contamination of the aggregate which prevents the collapse of the load bearing pyramid. Without "Typar" under the base, small particles of soil intermix with the individual pieces of aggregate because of water pressure or pressure alone. The particles of soil act as a lubricant between the pieces of aggregate, thus destroying at least the lower portion of the load bearing pyramid. This means instead of approximately 12" (30.5 cm) of properly loaded aggregate, there are approximately 9" (23 cm) of overloaded aggregate. Further overloading pushes the soil particles farther into the aggregate making it even more ineffective. "Typar" acts to separate the aggregate from the soil allowing the aggregate to lock together and perform its function.

Experience has shown that "Typar" also tends to allow the soil to improve itself after installation. Water is squeezed out of the soil and through the "Typar", thus providing a firmer, less jelly-like foundation. It will also be found that, in cases where compaction is practical, goal densities can be achieved with less effort.

An excellent summary of the theoretical considerations in the thickness design of flexible pavements is contained in "Highway Engineering Handbook", K.B. Woods, First Edition, pages 25-4 and 25-9. By the use of equations put forth by Boussinesq, Burmister, Nemark, Coulomb, and Rodin, investigators have proposed design procedures based on these theoretical considerations. This design procedure is based on the following assumptions:

1. The Corps of Engineers' CBR design curves indicate how much aggregate is required to support a given wheel load on a given soil.
2. Part of the design depth could be eliminated if there wasn't any contamination of the aggregate or plastic deformation of the subbase material.

The CBR contribution of 4 oz./sq. yd. (136 g/m²) of "Typar" was determined by laboratory investigations using CBR equipment. It was found to be **4% in CBR ranges over 1%.** The next question was, "Is this 4% additive over soil?" The answer is, "Yes!" Test roads were then built to verify the laboratory tests. These roads, plus experience through the years, have shown this figure to be conservative for soils of CBR of one and above.

Site Survey

A thorough survey of a construction site is very important to the quality of the aggregate base being installed. Geography is one of the first things to consider. Does the area have a rainy season? Does it freeze? Although it may be dry during construction, has adequate drainage been considered? Is freeze-thaw a consideration?

Frost susceptible material contains greater than 3 percent material finer than 0.02 MM (silts). When material contains these silts, two things happen. First, it attracts water through capillary action. Second, when the water expands through freezing there aren't any voids to expand into. This situation results in large area frost heaves or localized frost boils. Good quality road base aggregate is not susceptible to frost heaves until it is contaminated with silt. This contamination is minimized by using "Typar" between the aggregate base and sub base.

In the Spring, the top layer of sub base thaws first. Generally, this water cannot drain naturally due to the presence of adjacent ice. The bearing capacity of the fine grain soils is reduced. Field tests have shown that this loss can be 50% or more. Base aggregate mixes with the low strength subbase. Excessive surface deflection takes place. Complete pavement surfaces can break up or localized failure can occur in the form of "chug" holes. This situation can be eliminated or at least minimized by using "Typar" between the aggregate base and subbase.

Remember, the design of the base must be for the worst service conditions.

Are there local industries that have waste or slag materials that are good aggregates?

Topography is another consideration. Most of the ore, lumber, oil, and real estate that is easy to get at or build on has been taken or is fraught with environmental considerations. Prime spots for the use of "Typar" are in marsh, muskeg, hydraulic fill, old sanitary landfills, river deltas, or the flood plain of waterways. Any soils in these areas will be water borne or organic in origin. The end result is silt and clay soils having very fine particle size and very low load bearing ability. Their load bearing value when wet is drastically lower than when dry. Therefore, adequate drainage should be provided as soon as possible since the soils drain very slowly. Even if construction is months away, drainage should shart **now.**

Investigate the soil strata by digging a ditch or bore with a soil auger at least a foot below the overburden. If you hit better material below the overburden, it will be best to remove the overburden. If not, cut off all vegetation over 1" (2.54 cm), in diameter, remove large boulders, automobile bodies, etc., and build.

CBR Determination

Once soils at a construction site have been identified, the approximate load bearing value can be determined by observation or the CBR of the soil can be determined with instruments. Determination of California Bearing Ratio by the use of instruments is the preferred method (for all but the most experienced with soil characteristics). Actual conduct of the California Bearing Ratio Test is fairly time consuming and many times is quite expensive. If conduct of such tests is justified, a qualified Soils Engineer should be called in. Field and laboratory procedures for running California Bearing Ratios are appended for information. As our method deals primarily with fine grained soils having a CBR less than 15, a cone penetrometer is an excellent tool for the determination of CBR equivalency. A direct reading cone penetrometer was developed for the use of NATO Engineering Forces and is sold by Leonard Farnell & Co., Ltd., North Mgmms, Hatfield, Herts, AL9 75R, England. Calibration of this instrument has been verified by the Corps of Engineers, RAF and British Military Engineering Experimental Establishment. Another penetrometer, not quite as handy to use, is sold by Soiltest, Inc., 2205 Lee Street, Evanston, IL 60207. It is called Corps of Engineers Cone Penetrometer.

Select 10 random spots for every 1,000 square yards to be stabilized. If the area is not frozen and is wet, tests can be run in situ. **If the soil is abnormally dry, place a length of pipe over each spot as a standpipe and fill with water for 24 hours.** When taking soaked samples, cut the number of locations in half and take two readings at each location. If the ground is frozen, jack out 2 ft.^{3} (.06 m^3) of sample from five spots in 1,000 yd.^{2} (836 m^2), remove to a warm spot, and recompact in a five gallon (19 L) can. You may want to wait until spring! Take at least three readings from each spot; i.e., 2", 12", and 18" (5, 30, & 46 cm). Only one reading will be obtained in the five gallon can. Use the numerical average of your determinations as your design CBR.

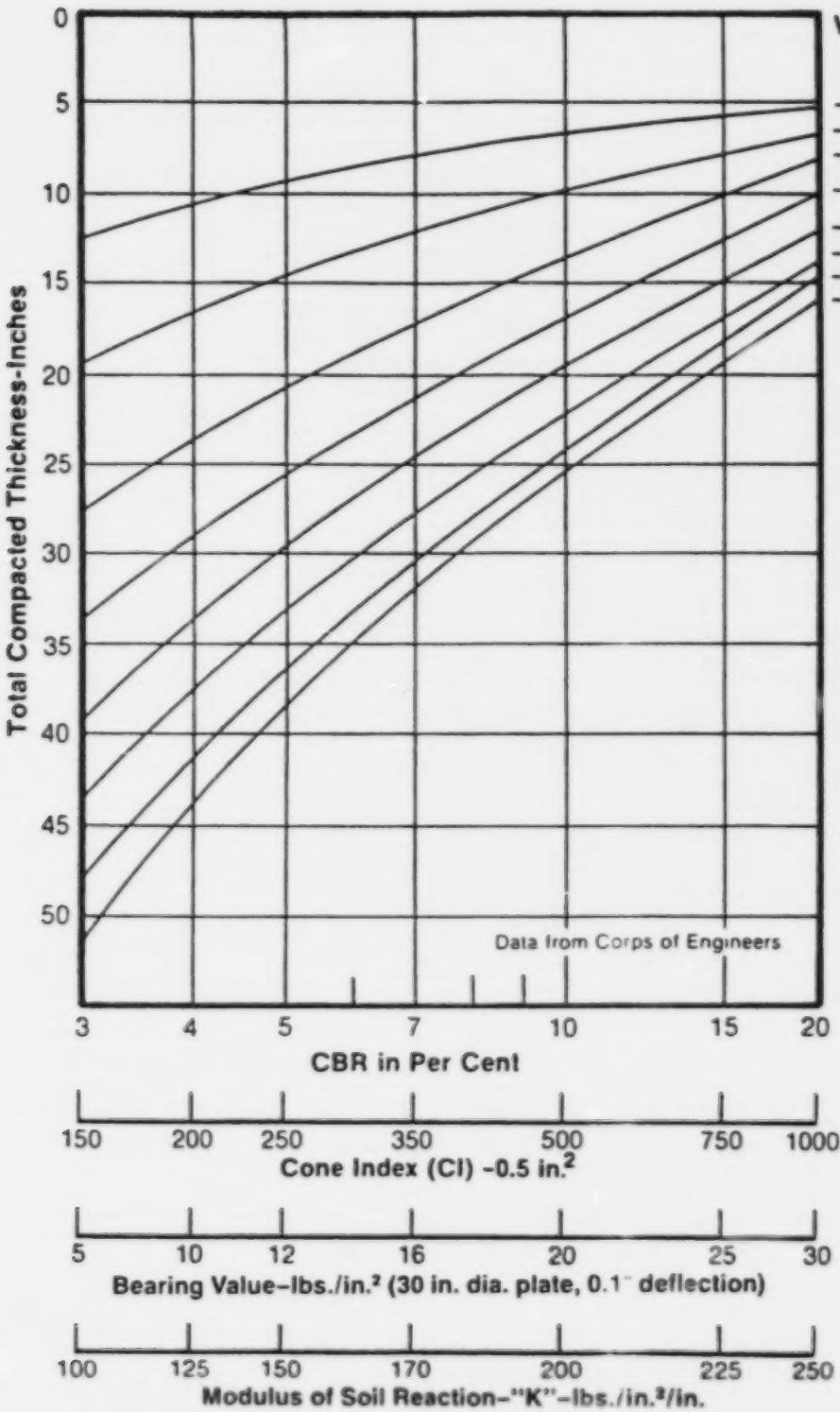
To determine equivalent CBR by observation, take a handful of material and rub it between the thumb and forefinger. Can you feel any hard particles? This will indicate the presence of sand. Dispose of the material. Does the residue on your fingers feel like talcum powder? If it does, there is clay or silt present. If this test indicates clay or silt, add some water and play with the material like you would putty. If the material can be molded and rolled into a thread with tensile strength, it is plastic. Put a small sample in a glass of water and stir. The silt will settle first and the finer clay particles will remain suspended indefinitely. Organic material will smell musty. Some particles of clay are only 10 angstroms in size and can be seen only with the most powerful of electron microscopes. The 200 mesh material will just pass through a nylon stocking.

At this point, a hole has been dug or bored and a determination has been made of the soil that lies beneath the overburden. Some of the soil has been handled and a rough idea of its physical characteristics has been determined. Using the appended soil diagrams and these soil characteristics, the type of material on the construction site can be determined.

First consider the AASHO, FAA, and Unified Soil Classification in **Figure 1.** Prior work done at the site by a soils engineer may also be available. This work may have resulted in a soil classification including Liquid Limit, Plastic Limit, and Plasticity Index. If so, check charts **(Appendices A & B)** and obtain CBR. This work may have resulted in a Bearing Value or Modulus of Soil Reaction. **Figure 2** shows the correlation of these values with CBR. The soil characteristics chart describes the soils and their CBR.

After an intelligent estimate of the CBR of the construction site soil has been determined. Take a final look around the site. Has the test hole filled with water, indicating a high water table and the need for subgrade drains? Do spots have lush vegetation indicating wet soft spots? Walk the site completely. The load bearing capacity of the soil can be roughly judged from how it feels underfoot.

Figure 2 Correlation of Bearing Value, Modulus, and Cone Index with CBR.



Thickness in Inches		
Load	CBR	
Kips	1	2
4	22	16
8	31	22
10	35	25
15	43	30
22	52	36
30	60	42
40	70	48
50	78	54
60	86	59
70	93	63

Note: Correlation variable, but within limits of method.

Traffic Survey (Wheel Loads)

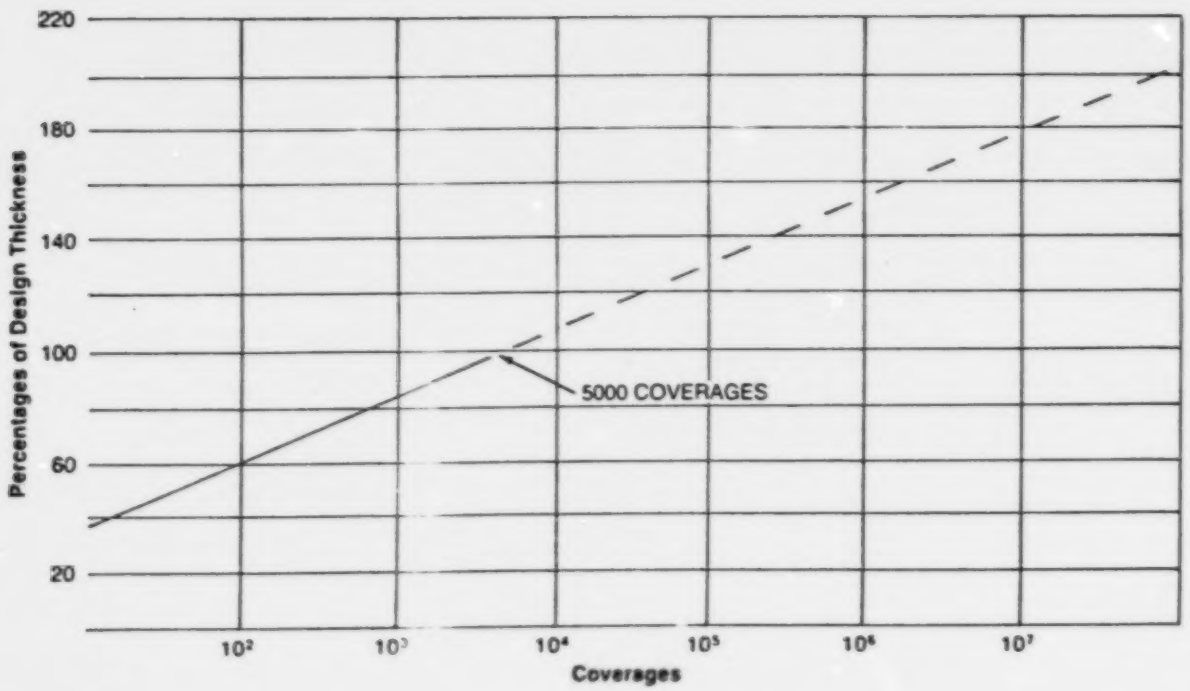
What type of vehicles will traverse the road, storage yard, or parking lot? What are their wheel loads? Is the aggregate base to have useful life of one year or 20 years? Should the job be attractive or just serviceable? What are the environmental considerations? Before making a judgment of design wheel load, realize that a wheel load is defined as: (1) one-half of the axle load regardless of the number of tires; and (2) an axle load is determined by dividing the gross weight of the vehicle by the number of axles. When the major load is concentrated on one axle, such as a log stacker, it is an exception to the rule. In determining wheel load, assume that any vehicle that will ride on public streets has a maximum wheel load of 7-9,000 lbs. For other vehicles, the wheel loads will be available from the user or the manufacturer.

What sort of service life is expected from the roadway? The CBR Tables are set up for life of 5,000 coverages, involving axle loadings of 18,000 lbs. or 9,000 lbs./wheel. Stick with this basis unless there's a shortage of funds or service life is only for a couple of months. **Figure 3** indicates how much can be taken out or added to the design depending upon service life.

Aesthetic considerations will occasionally pop up on a job, such as a residential driveway or a rustic, very posh, parking lot. First, support fabric of "Typar" will not allow soil to come to the surface and discolor the aggregate. Just any rock will not do. Well graded aggregate with fine dust wet down and compacted on the surface should be used. In some coastal areas, shell is an available and satisfactory substitute. Specially colored stone is available as surface material.

Environmental considerations are becoming more and more important in the construction of haul roads. Removal of the overburden opens the way for soil erosion. If 6" or less of overburden is involved in temporary road construction, let it lie. When the road is in use, fines will not be pumping to the surface with consequent stream siltation.

Figure 3 Design Reduction and Decreased Service Life



Final Design—Why "Typar"

There may or may not be a choice of aggregate. Whatever is used must be of better quality than the soil the road is built on. Surfacing materials run generally as follows from best to worst:

Graded Aggregate
Crusher Run
Pit Run
Slags
River Run with sand or clay
River Run gravel
Sand

The largest stone should not be larger than 1/3 the total thickness. Material smaller than 200 mesh should be a maximum of 25% and a minimum of 15%. Fines passing the #4 sieve should not have a liquid limit greater than 30 nor a plasticity index greater than 6. The aggregate should have a uniform gradation from the largest to smallest. Many times an on-site blend of fly ash, bottom ash, sand, clay, and river run gravel can be made to obtain the optimum gradation. Sharp aggregate is the best. The idea is to lock the whole mass together under load so that the ideal pyramid shape of load distribution mentioned under "The Function of 'Typar'" is retained. Equivalency factors have been assigned to various materials. For example, compactible sand is 38% (2.6" = 1.0") as effective as crushed limestone. Asphaltic concrete is 150% (1" = 1.5") more effective than crushed limestone.

The thickness efficiency of various surfacing materials are tabulated below:

Material	Thickness Efficiency*
Asphaltic Concrete	150%
Hard Rock-Scratch Knife	100%
Med. Rock-Scratch Coin	80%
Shell	70%
Ripable Hardpan	54%
Soft Rock-Scratch Fingernail	44%
Loose Gravel, Sandy Gravel, and Compactable Sand	38%

*Based on the square root of bearing capacity.

By one means or another, an equivalent California Bearing Ratio of the soil and an equivalent wheel load for the vehicles has been obtained. A CBR chart is appended which covers wheel loads up to 70,000 lbs.

The compacted aggregate thickness can be calculated from the formula:

$t = \text{constant} \times \sqrt{WL}$

t = thickness in inches

WL = Wheel Load in pounds

The constants which apply to our range of application are as follows:

CBR	Constant	CBR	Constant
1	.346	8	.111
2	.242	9	.101
3	.196	10	.100
4	.168	12	.086
5	.149	15	.072
6	.130	17	.067
7	.121		

To use centimeters and kilograms, multiply constant by 3.77.

Generally speaking, support fabric of "Typar" has very little value-in-use when used with soils of 10 CBR or greater except where the cost of aggregate is very high. For example:

Wheel Load = 9,000 lbs.
CBR = 4

— **From Chart:** Compacted pavement thickness = 16"
— Add 4 CBR units for using "Typar": CBR = 8
— Pavement with "Typar"—11"
Aggregate Savings = 16"-11" = 5"
— Aggregate Cost: $5.40/yd.^{3} or $5.40 ÷ 36 × 1.25* = $.19/in./yd.^{2}
Savings = 5 × $.19 = $.95/yd^2

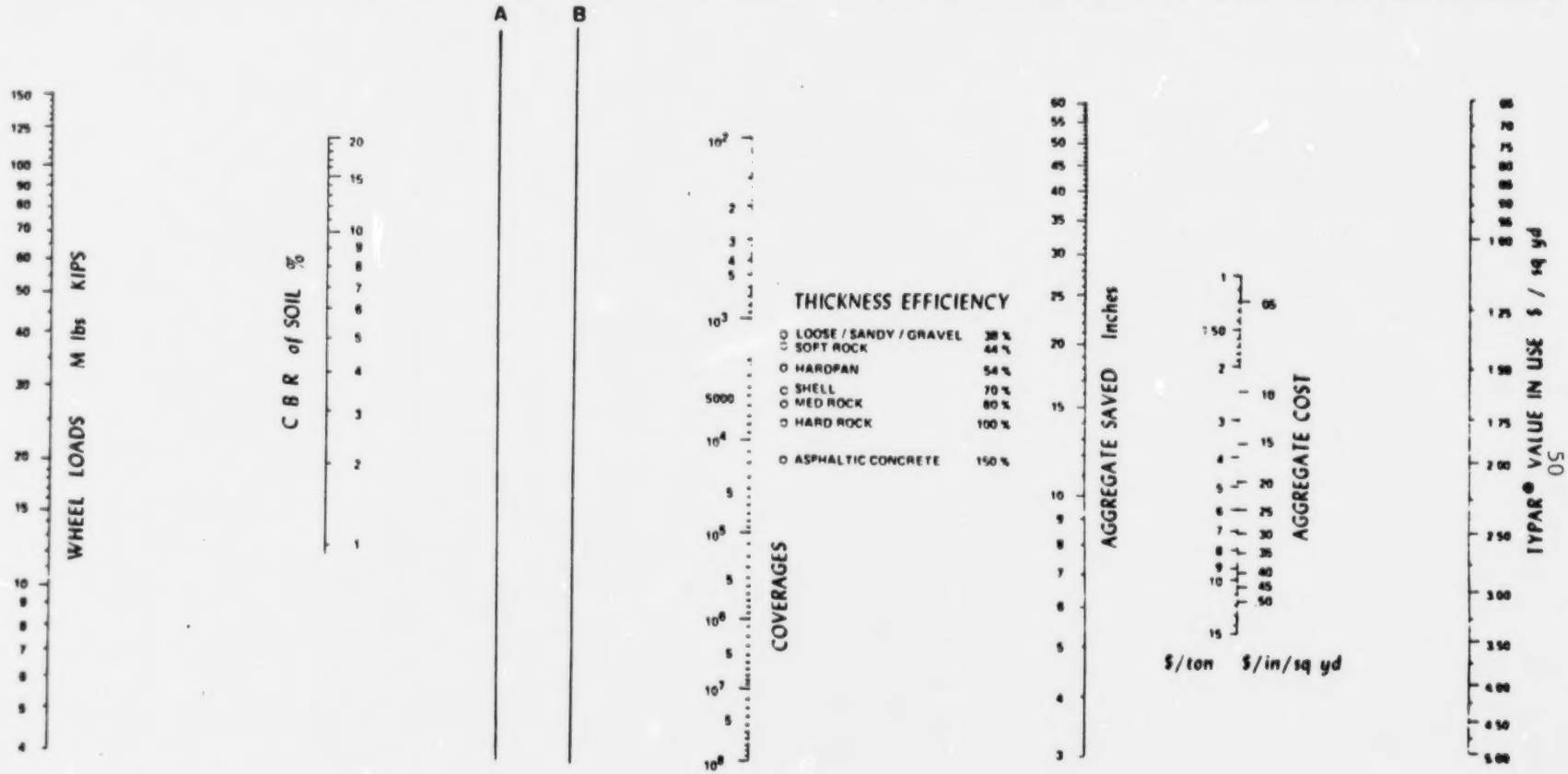
Subtract cost of "Typar" from the savings to arrive at actual savings. Under no circumstances use less than 5" of aggregate over "Typar"—Grading tolerances are + .1 ft.

Regardless of aggregate savings, "Typar" will add all weather construction insurance to any marginal soil; i.e., <30 CBR.

*25% compaction factor for crushed stone.

VALUE IN USE STYLE 3401 TYPAR®
support filter fabric

CIVIL ENGINEERING SUPPORT APPLICATIONS



NOMOGRAPH INSTRUCTIONS

1. Connect "Wheel Load" and "CBR" points and continue line to Line "A"
2. Connect Line "A" point and "Coverages" point establishing a Line "B" point
3. Connect Line "B" point and "Thickness Efficiency" point and continue line to "Aggregate Saved" line
4. Connect "Aggregate Saved" point with "Aggregate Cost" point (compacted & in place) and continue line to "Value-In-Use" line
5. Subtract cost of TYPAR from "Value-In-Use" to determine dollars saved using TYPAR

Typical Physical Fabric Properties

		GEOLON							FILTER CLOTHS		
		Standard Stabilization		High Performance Stabilization					NICOLON		
		150	200	400	600	700	1250	1250X	70/06 (60109)	40/30 (60709)	100/08 (60209)
Composition	Warp	PP Tape	PP Tape	PP	PP	PP	PP	PP	PP	PP	PP
	Fill	"	"	"	"	"	"	"	"	"	"
Weight-oz/yd² ASTM D-1910		3.4	4.0	7.2	15.0	8.4	22.0	27.0	7.2	6.4	7.4
Tensile Strength – lbs ASTM D-1682 (Grab Test)	Warp	150	200	375	540	450	1,150	1,150	385	260	400
	Fill	150	200	250	440	375	250	580	250	225	300
Bursting Strength lbs/in² ASTM D-751 MULLEN-Average Test Result		330	375	420	1370	800	1,500	1,600	540	500	575
Uniaxial Strip Tensile Strength Mobile Dist. Corps of Engrs * 6"x12" strip, 1% min. strain rate	Warp	–	160	250	350	300	1,000	–	–	–	–
	Fill	–	160	175	250	300	200	–	–	–	–
Puncture Strength – lbs ASTM D-751 MODIFIED		50	80	170	250	200	225	225	150	100	240
Elongation at Break ASTM D-1682	Warp %	20	20	30	18	25	18	18	25	30	34
	Fill %	20	12	18	18	25	18	18	30	25	32
Tear Strength Trapezoid ASTM D-2263	Warp	35	55	80	200	125	320	320	90	55	90
	Fill	35	55	65	200	110	140	225	45	45	40
E.O.S. U.S. STANDARD SIEVE °85		70	70/100	30-40	30-70	30-40	30-40	30-70	70	40	90-100
% OPEN AREA		2-8	2-8	10-15	2-8	10-15	6-12	2-8	5-10	24-30	6-9
Thickness Mils ASTM D-1777		15	18	29	102	24	100	100	18	30	17
Abrasion Resistance – lbs ASTM D-1175 Modified	Warp	–	–	90	250	200	600	600	100	120	175
	Fill	–	–	60	225	200	200	300	70	95	150

*Test Procedures are described in the paper, "Testing of Geotechnical Fabric for Use as Reinforcement" by Haliburton, Anglin, and Lawmaster, *ASTM Geotechnical Testing Journal*, Vol 1, No 4, Dec 1978, pp 203-212.

To the best of our knowledge, the information contained herein is accurate. However, Nicolon Corporation cannot accept liability of any kind for the accuracy or completeness thereof. Final determination of the suitability of any information or material for the use contemplated, of its manner of use, and whether the suggested use infringes any patents, is the sole responsibility of the user.

The Geotextile Leader since 1958

NICOLON CORPORATION

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Norcross/Atlanta, Georgia 30071
Phone 1-800-241-9691
In Alaska, Hawaii and Georgia (404) 447-6272

Physical Properties — Style 3401
Road Support, Soil Stabilization & Filter Fabric Applications

Weight	4.0 oz./yd.²	ASTM D1910-64 (1975)*
Thickness	15 mils	ASTM D1777-64 (1975)
Grab Tensile	135 lbs	ASTM D1682-64 (1975)
Elongation to Break	62%	ASTM D1682-64 (1975)
Modulus	1200 lbs	ASTM D1682-64 (1975)
Trapezoidal Tear	74 lbs	ASTM D2263-68
Puncture Strength	50 lbs	ASTM D751-73
Mullen Burst	200 psi	ASTM D774-46
Abrasion Resistance	42 lbs	ASTM D1175-71
Specific Gravity	0.95	
Equivalent Opening Size (EOS)	70 to 100 U.S. Std Sieve	Corps of Engineers/ ASTM D422-63 (1972)
Flux	230 gal./ft.²/min	EURM-100**
Coefficient of H_2O Permeability (K)	2×10^{-2} cm./sec	EURM-100**

Deformation Resistance

Strain %	Stress lbs./in.	Stress lbs./in./oz./yd.²	Set %
5	22.8	5.7	0.0
10	29.2	7.3	1.2
15	32.4	8.1	1.9

Shrinkage

270°F	1%
300°F	3%
340°F	Melts

NON-PROPRIETARY DESCRIPTION:

A sheet structure composed entirely of preferentially oriented isotactic polypropylene continuous filaments thermally bonded mostly at the crossover points and weighing 4.0 ± 0.3 oz./yd.²

PRODUCT RANGE — STYLE 3401

Width* (in.)	Roll Length** (yds.)	Roll Diameter (in.)	Roll Weight** (lbs.)	Roll Sq. Yds.**
151	100	9	105	420
151	300	14	315	1,260
151	1,000	25	1,050	4,200
197	100	9	137	547
197	300	14	410	1,640
197	1,000	25	1,368	5,470

*Custom widths available on request

**These product range numbers are nominal dimensions and weights. Actual lengths, weights and areas are ±3% of the nominal numbers.

APPENDIX D.

METHODS OF TESTING GEOTEXTILES

10.1 Tensile Strength

There are many tests in use that measure the tensile strength of a geotextile. Some are standard tests that are used in the textile industry, while others are new tests developed by civil engineers. The new tests were devised because the most popular tests used by the textile industry are unidirectional. However, in geomechanical applications, it is important to establish the multidirectional behaviour of the fabric. Tests have shown that the tensile strength of a fabric is increased as compressional stress is applied perpendicular to the plane of the fabric.

10.2 Soil-Geotextile Friction and Adhesion

The amount of grip between soil and a textile is very important in road strengthening applications. This property can be measured using a shear box test. The box may be used to perform either a shear test or a pull-out test, as shown by Figure 2.